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Environmental impact of chemical and mechanical weed control in agriculture

- a comparing study using Life Cycle Assessment (LCA) methodology

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ABSTRACT

In this paper, two farming systems have been compared in a Life Cycle Assessment, LCA. The LCA is a methodology that allows the viewer to analyse a product or a service through its entire life cycle.

The Swedish government has formulated 15 environmental goals. Amongst these, it is stated that the amount of chemicals used in agriculture should be minimised. It is therefore of great interest to look at alternative ways of fighting weeds. In this study a farming system with chemical weed control is compared to a farming system with mechanical weed control regarding energy use and environmental impact. The base of comparance, the functional unit, was the total yield from all crops in a determined crop sequence during one year.

Data for the chemical scenario was collected from Fäcklinge Fors farm in Tierp, Sweden. Some data were collected from literature in order to give the study a more general validity. The farm in Tierp has a crop sequence that also would be suitable for a farm with mechanical weed control (barley, ley I, ley II, winter wheat, oats, potato). The mechanical scenario was thus a hypothetical switch to a mechanical weed control system at the same site. Most other conditions were the same for the two scenarios, for example fungus and insect control. The yields on the other hand were assumed to differ between the scenarios. Since the functional unit was based on the amount of products, the area of grown land differed between the scenarios.

The results indicated that the mechanical scenario had a larger contribution to the impact categories energy, global warming, eutrophication, acidification and photo-oxidant formation. But the differences between the scenarios were small compared to the farming system in total. The study showed that a mechanical weed control system not necessarily cause much larger emissions or energy use, but has the great advantage of not using herbicides.

Amongst the crops, oats showed the largest diversion between the chemical and the mechanical scenario. This due to the fact that the heaviest direct weed control, stubble cultivation was done here.

The production of mineral fertilisers had the largest contribution to the global warming potential; the weed control had only marginal effect on the results. The nitrate leaching had the largest influence on eutrophication. In the acidification category, field operations were the largest contributor. The field operations were also the largest contributor to photo-oxidant formation. The energy usage in the mechanical scenario was only 4% larger than in the chemical scenario.

SAMMANFATTNING

I denna studie jämfördes två odlingssystem i en livscykelanalys (LCA). LCA är en metod där en produkt eller tjänst studeras genom hela sin livscykel.

Sveriges riksdag och regering har antagit 15 miljömål för att nå en hållbar utveckling. Bland dessa återfinns en minskad användning av kemikalier i jordbruket. Det är därför intressant att studera alternativa metoder för att bekämpa ogräs. I detta examensarbete har två odlingssystem jämförts, ett med kemisk och ett med mekanisk ogräsbekämpning, med avseende på miljöpåverkan och energianvändning. Basen för jämförelse, den funktionella enheten, var den totala skörden från alla grödor i en växtföljd under ett år.

Dataunderlag till det scenariot med kemisk bekämpning hämtades från Fäcklinge Fors gård i Tierp, Sverige. Vissa siffror inhämtades dock från litteratur. Gården i Tierp har en växtföljd som även skulle passa bra för mekanisk ogräsbekämpning (korn, vall I, vall II, höstvete, havre, potatis). Det mekaniska scenariot var alltså en hypotetisk omläggning till mekanisk ogräsbekämpning från dagens system. Alla andra förutsättningar antogs vara de samma, till exempel handelsgödsel, fungicider och insekticider. Skördarna antogs däremot skilja mellan scenarierna. Eftersom den funktionella enheten var baserad på massa, så skiljde sig den odlade arealen åt mellan det kemiska och mekaniska scenariot.

Resultaten indikerade att det mekaniska scenariot gav ett högre bidrag till miljöpåverkanskategorierna energi, växthuseffekt, eutrofiering, försurning och fotooxidansbildning. Skillnaden mellan scenarierna var dock små om man jämför med odlingssystemen i sin helhet. Denna studie visade att ett odlingssystem med mekanisk ogräsbekämpning inte nödvändigtvis orsakar mycket större utsläpp eller energianvändning än ett system med kemisk ogräsbekämpning, men har den stora fördelen att inte använda herbicider.

Mellan de olika grödorna fanns stora skillnader. Havre visade störst skillnad mellan det kemiska och mekaniska scenariot, vilket beror på de tunga mekaniska insatserna i den grödan, främst stubbebearbetning.

Produktionen av handelsgödsel bidrog mest till växthuseffekten medan ogräsbekämpningen hade marginell påverkan. Utlakningen resulterade i det största bidraget till övergödningen. Till försurning bidrog operationer på fält mest. Fältoperationer var även den största bidragande faktorn till fotooxidansbildningen. Energianvändningen var endast 4 % högre i det mekaniska scenariot jämfört med det kemiska.

FOREWORD

This project was conducted as a Master's Thesis at the department of agricultural engineering at the Swedish University of Agricultural Science (SLU).

The initiator of the project was the Swedish Institute for Food and Biotechnology (SIK) in Gothenburg, Sweden.

SIK and SLU are involved in the program Sustainable Food Production, FOOD 21 (in Swedish: MAT 21). The overall long-term goal of the FOOD 21 program is to define optimal conditions for sustainable food production that generate high quality food products. This paper forms a part of the MAT 21 program.

I would very much like to thank Berit Mattsson (SIK), Per-Anders Hansson (SLU) and Maria Wivstad (SLU) for their supervision and guidance throughout the project. I would also like to thank Hans Fredriksson for answering all of my questions. Finally, I would like to thank my husband and children for their patience and support at all times during this project.

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1 INTRODUCTION

Weeds have always been a problem in cultivation. More specifically weeds lower the yields and the quality of the yield. Weeds can also be carriers of infections, fungus and other diseases, which can contaminate the crops. Large number of weeds can also cause cereal to lodge.

Weeds can also be positive, for such things as biodiversity. Increasing the number of species and attracting wild animal can be a high priority. In this paper, though, weeds are something we want to minimise. The weeds have to be regulated, not causing harvest decrease or other problems.

There are in principal two ways of fighting weeds; direct and indirect. Direct means taking action against the weeds for example by ploughing, hoeing, harrowing, hand plucking, flame treatment and by spraying herbicides. Indirect weed control can for example be a well-planned crop sequence. It also includes choosing crops that are competitive and to use clean seed. Taking technical cropping measures, such as delayed sowing, increasing or decreasing row distance and adjusting the amount of seed are other examples of indirect weed control (Fogelfors, 1995).

Up to World War II a lot of effort was put into indirect weed control, since weeds were a limiting factor for the yield. Then something changed; the herbicides were introduced. This made it possible to have a non-diversified crop sequence without any weed problems. But the negative effects of this type of farming systems have proven to be many. Not only is it dangerous for the farmers to handle the chemicals, but it is also damaging for the environment. It affects biodiversity in a negative way and can give rise to new compositions of species. Traces of herbicides are also found in harvested crops and ground- and surface waters (Fogelfors, 1995; Gummesson, 1992).

The Swedish government has formulated an environmental policy. In this policy, that contains 15 goals, it is among other things stated that by the year 2005 twenty percent of arable land should be organically farmed (Miljömålsportalen, www). In organic farming herbicides are not allowed. In the environmental goals it is also stated that the usage of chemicals shall be minimised in order to maintain a non-toxic environment. It is therefore of great interest to investigate alternative ways of fighting weeds, such as mechanical weed control. But what impact does a mechanical weed control system have on the environment? This is the main question in this paper.

Weed control is only a part of the whole farming system. Whatever conclusions made in this paper, it does not determine whether one system or the other is more suitable. What effect agriculture has on the environment depends on a number of factors all woven together in a complicated pattern.

1.1 Goal and scope

My objective is to study the difference between a farming system with chemical weed control and a farming system with mechanical weed control in a life cycle assessment (LCA).

2 WHAT IS A LIFE CYCLE ASSESSMENT?

2.1 Methodology

A life cycle assessment (LCA) is a methodology used to study the potential impact on the environment caused by a chosen product, service or system. The product is followed through its entire lifecycle. The amount of energy needed to produce the specific product as well as the environmental impact is calculated. The life cycle assessment is limited by its outer system boundaries, Figure 1. The energy- and material flows across the boundaries are looked upon as inputs (resources) and outputs (emissions) (ISO 14041). In other words, the LCA maps the environmental impact and energy use caused by the product but also the impact outside the system, for example by extracting raw material.

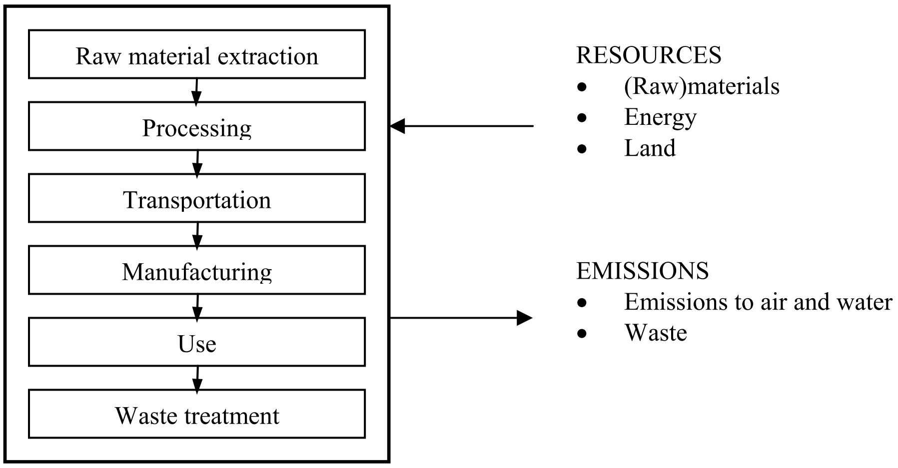

Figure 1. A typical life cycle through an LCA-perspective (ISO 14041).

A methodology for the proceedings of a life cycle assessment is standardised in ISO 14000-14043. According to this standard a life cycle assessment consists of four phases. The **first** phase includes defining a goal and scope. This should describe why the LCA is carried out, what boundaries the system has and the functional unit. The functional unit is a very central concept in LCA and will be discussed again later. The **second** phase of an LCA is the inventory analysis i.e. gathering of data and calculations to quantify inputs and outputs. The **third** phase is the impact assessment where the data from the inventory analysis are related to specific environmental hazard parameters (for example CO_2- equivalents). The **fourth** and last phase is the interpretation. The aim of the interpretation phase is to analyse the result of the study, evaluate and reach conclusions and recommendations (Lindahl et at, 2001).

2.2 System Boundaries

If an LCA is carried out on a farming system Figure 1 can be modified. The life cycle for a farming system does not necessarily go from “cradle to grave” but rather from “cradle to farm-gate”.

Since industrial production of capital goods, such as machinery and buildings has little effect on the results, they are usually left out in these kinds of LCAs (Mattsson, 1999). But the scope of the study is the determining factor whether or not to include machinery and buildings.

2.3 Functional unit

The functional unit is a very central concept in an LCA. It is a unit that relates the environmental effects and energy used to the main function of the system or to what the system delivers. For example the functional unit can be 1 kg of meat or 1 m^2 floor. The functional unit is the base of comparison. According to the Nordic Guidelines on Life-Cycle Assessment (Lindfors et al., 1995) the functional unit is "a relevant and strict measure of the function that the system delivers and is the basis for the analysis. All data will be related to the functional unit".

There have been several studies done on agricultural products, for example for one kilo of winter wheat. By defining the functional unit in mass, the quality or function of the product is not taken into account. If the functional unit is 1 kg of meat, one cannot compare beef and pork since the function of beef and pork is different (they have different nutrient values).

In order to make a just comparison of mechanical and chemical weed control it can be insufficient to investigate a single crop. This is due to the fact that the success of the mechanical weed control depends on a number of accumulating factors. For example what weed control is done in the preceding crop affect the following crop. Further, what indirect measures (such as crop sequence) has been taken also affect the number and composition of weeds that needs to be fought. If instead a whole crop sequence in the farming systems is investigated it is more likely to discover true differences between chemical and mechanical weed control in an LCA.

2.4 Allocation

In practice, very few production processes have a single input and output for a specific product. Often more that one product is produced and it is therefore difficult to determine what product causes what emission. Sometimes by-products are created that can be used as raw material in other systems or be re-cycled within the studied system. This of course makes it difficult to calculate the impact of the product. For example, a coal fuelled heat and power station produces both heat and electricity. How are the emissions to be divided between the two products? There are several suggested solutions for allocation problems, for instance by the ISO-standard (ISO 14041) that divides the allocation procedure into three steps:

Step 1: Whenever possible allocation should be avoided. This can be done by dividing the system into sub processes or by expanding the product system to include the additional functions.

Step 2: Were allocation cannot be avoided; the allocation should be made upon the underlying physical relationships.

Step 3: Were physical relationships alone cannot be established; the inputs should be allocated between the products in a way which reflects other relationships between them. For example by economical value.

In agricultural production LCAs allocation problem often arise in connection with straw handling. Whether or not the straw should be allocated depends on if the soil is included within the system boundaries. If the soil is included then straw that is harvested and sold is considered as a co-product and should be allocated. Straw that is reincorporated does not cross the system boundaries.

If the soil on the other hand is not included within the system boundaries, all harvested straw must be considered as co-products. Whether the straw is sold or reincorporated is not relevant as this is an activity that takes place outside the system (Cowell, 1995).

2.5 Impact assessment

The impact assessment is performed when all data has been collected in the inventory analysis. Very often the inventory generates a large amount of data and it is often necessary to do an impact assessment in order to reach an overall impression of the results. The impact assessment consists of three steps (Figure 2): classification, characterisation and valuation (Lindahl et al., 2001).

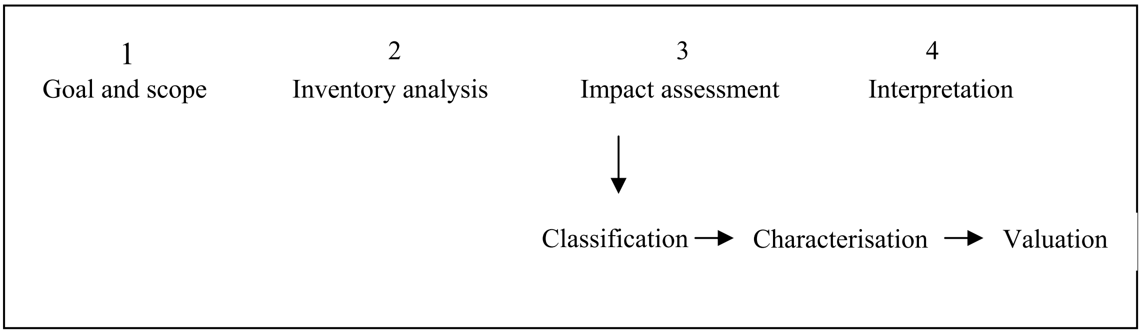

Figure 2. Schematic description of LCA-procedure

The *classification* is done by sorting all the data into different categories. For example are emissions of CO_2 (carbon dioxide) and CH_4 (methane) sorted into the global warming category. There are many different impact categories, divided in three main branches: resources, human health and ecological impact (Lindfors et al., 1995):

- Resources
  - -Energy and material
  - -Water
  - -Land
- Human health
  - -Toxicological impacts (excluding work environment)
  - -Non-toxicological impacts (excluding work environment)
  - -Impacts in work environment
- Ecological impacts
  - -Global warming
  - -Depletion of stratospheric ozone
  - -Acidification
  - -Eutrophication
  - -Photo-oxidant formation
  - -Ecotoxicological impacts
  - -Impact on biodiversity

An emission can have impact on several categories; for example CFC (chloride fluoride carbonate, also known as freon) has effects on global warming and depletion of stratospheric ozone, and must be included in both impact categories.

The aim of the *characterisation* is to quantify how much each emission contributes to an impact category. For example, as mentioned earlier both CO_2 and CH_4 effect the global warming. But CH_4 has a stronger effect on global warming per kg substance. 1 kg of CH_4 has the same effect on global warming as 21 kg of CO_2. In order to adjust this, all emissions are multiplied with equivalent factors.

In the *valuation* all the inventory results are aggregated to one figure. A valuation is not always done in LCAs and it is not a necessary step. In the valuation the different impact categories are weighted together. This of course, is not easy. For instance, what is most important, global warming or eutrophication? Lindahl et al. (1995) concludes: “This step can not be entirely based on traditional natural science. Political, ethical and administrative considerations and values are used in this step. Since different people and societies have different political and ethical values, it can be expected that different people will sometimes come to different conclusions based on the same data.” No valuation is done in this study.

3 DEFINITION OF THIS LCA

3.2 Setting up the scenarios

The LCA consists of two scenarios that will be compared. In the first scenario a conventional farming system will be analysed. The second scenario is the same as the first scenario, except for the weed control, which in this case is handled mechanically without chemicals.

The inventory analysis will be carried out in two steps. The data will be collected both by studying literature and by studying a conventional farm in Tierp, in the province of Uppland in Sweden. The data that will be used in the LCA is a mixture of the two sources. This is done in order not to lock up the study to a particular site or farm, but to make it more generally applicable.

The Tierp farm is selected on basis of the crop sequence that is established as theoretically suitable for a mechanical weed control system. This might seem contradictory as the farm also represents the base for the chemical scenario. But it is a necessity to keep the crop sequence alike in the two scenarios in order to facilitate interpretation and reach comparable results.

The mechanical farming system will be a hypothetical switch from the chosen chemical system. As the crop sequence already is adjusted for a mechanical weed control system, no changes have to be made in that area. Further, most other conditions (such as tillage and fungus control) will be the same in the mechanical scenario.

The working order in this study is hence; select a crop sequence that is theoretically suitable for a mechanical weed control farming system. After that, choose a conventional farm that keeps this crop sequence. Then define the chemical and mechanical scenarios based upon literature studies and by studying the Tierp farm.

3.3 System boundaries

The LCA will include everything that is carried out on a chosen limited field. There are several inputs and outputs, which is illustrated in Figure 3.

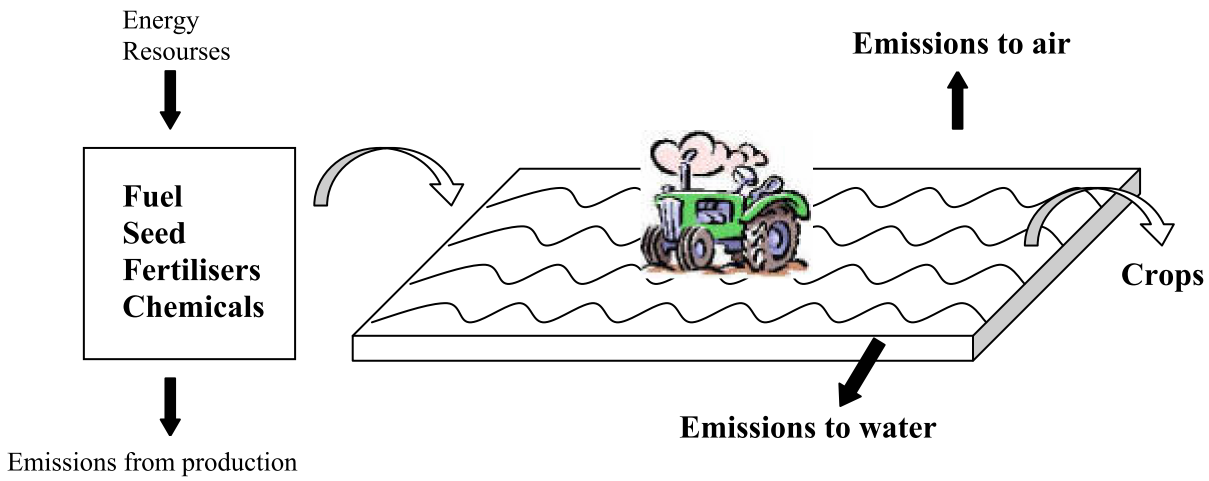

Figure 3. Inputs and outputs to field.

3.4 Functional unit

The functional unit in this study is defined as **the total yield from all crops in a crop sequence during one year on a farm**. This means that the yields must be the same in both the mechanical and the chemical scenario in order to have the same functional unit. Since the mechanical scenario is expected to give rise to lower yields per hectare it is possible that a larger area of land will have to be cultivated in the mechanical scenario. In the chemical scenario 1 hectare of land for each crop will be studied during a year. In the mechanical scenario the use of land will be larger to fit the yield in the chemical system. The functional unit is further specified in chapter 4.3.3. It is there stated that **the functional unit is 49 500 kg of agricultural products: barley (4 436 kg), ley (13 172 kg), winter wheat (5 657 kg), oats (4 021 kg) and potato (22 212 kg).**

3.5 Impact categories

In the following chapters the different impact categories that will be used in this study are briefly described. The characterisation factors for all the substances that are studied are presented in Appendix 1.

3.5.1 Resources

The most important non-renewable resources used in agricultural production are phosphorus and fossil fuels. In this study the resource energy will be discussed. Energy will be divided into three groups; diesel, electricity and total energy use. Other categories that can be included in resources are land and water. There is no irrigation on the studied farm, and since all other water use is the same in both scenarios, water resources will not be discussed in this study.

3.5.2 Global warming

The sun warms up the earth. The surface of the earth emits some of the energy from the sun as heat radiation. The atmosphere consists of a number of gases that absorps some of the heat radiation from the earth's surface, but some of the radiation "bounces" back to earth. This is known as the green house effect. This is a natural effect that keeps the temperatures on earth on the right level for our survival. But if the amount of greenhouse gases increases in the atmosphere due to human activities, that balance is disturbed. The effects of an increase of green house gases are widely debated. Many scientist believe that the temperatures on earth will rise, which would have devastating effects on the climate and on the terms of life (Bernes, 2001).

Substances that increase the global warming are for example carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is emitted in large quantities when fossil fuel is combusted.

Global warming is calculated as CO_2-equivalents in this study.

3.5.3 Eutrophication

Eutrophication occurs when the flow of nutrients to a water system is larger than normal. When the amount of nutrients increases, the growth of certain populations in the water system increases for example algae. When these populations are decomposed large amount of oxygen is needed, causing oxygen depletion at the sea or lake bottoms. The substances that mainly nitrify the water are nitrogen and phosphorus emitted via water but also via air. Also organic matter in water (measured as BOD or COD) increases the eutrophication (Bernes, 2001).

Eutrophication is calculated as O_2-equivalents in this study.

3.5.4 Acidification

Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) that are emitted to air are spread in the atmosphere. They are combined with other substances in the atmosphere and turned to acids. The acids are solved in water drops and reach the surface of the earth as rain or fog. These "acid rains" lower the pH of soils and water which can lead to fish being wiped out, forests being drained of nutrients and ground water being contaminated with metals. This is true for large areas of Sweden that has very little lime in the bedrock. Bedrock, which contains lime, can neutralise the acid rain, and is not in the same extent affected.

Emissions of sulphur dioxide mainly come from industrial production. In Sweden, these sorts of emissions have been significantly reduced during the past 20 years. The main sources of nitrogen oxide pollution are road traffic and industries (Bernes, 2001).

Acidification is calculated as mole H^+-equivalents in this study.

3.5.5 Photo-oxidant formation

Ozone is formed in the presence of sunlight in the atmosphere. The amount of formed ozone depends mainly on how much nitrogen oxides and organic compounds the atmosphere contains. Increased levels of ozone may cause effects on human health, ecosystems and damage crops (Cederberg, 1998).

Photo-oxidant formation is calculated as C_2H_2-equivalents in this study.

3.5.6 Pesticides

Another important impact category in this type of study is pesticide use. The amount of used pesticides can be quantified, but the dangerousness of pesticides is more difficult to determine. Several methods have been developed to calculate the impact of pesticides on human health, aquatic and terrestrial ecosystems (Margini et al., 2002). In this study though, only a general view of how dangerous pesticides are will be given. In the impact assessment the amount of pesticides used in the scenarios will be accounted for.

In order to determine the dangerousness of pesticides it is important to establish the mobility of the pesticides. In general, pesticides can be transported in the environment in five different ways: (see also Figure 4)

1. Wind-drift
2. Volatilisation
3. Deposition
4. Run-off
5. Transports in soil and water (for example via leaching and drainage)

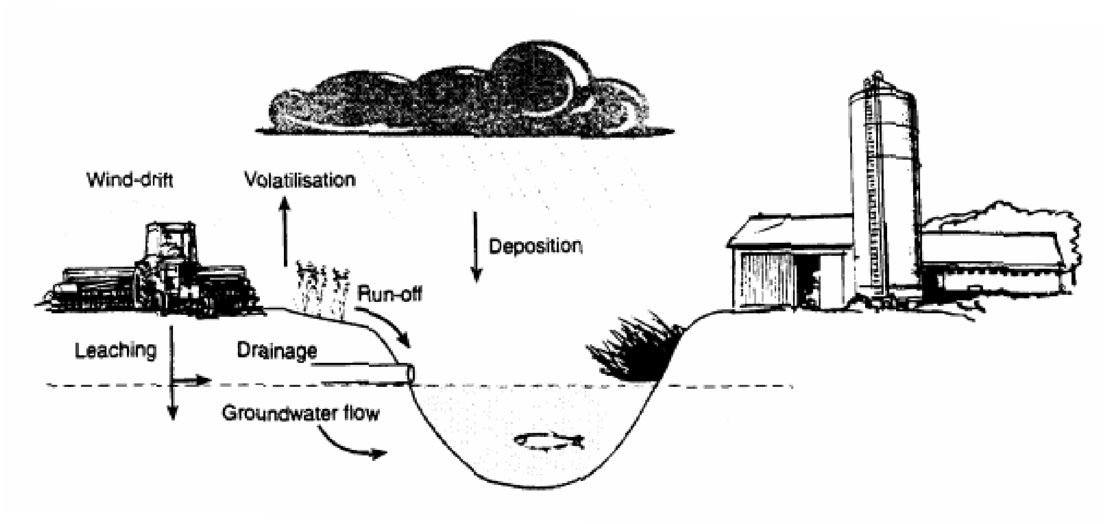

Figure 4. Principal environmental pathways by which agricultural pesticides may be transported to surface waters. After Kreuger (1999).

Further, the pesticides can be spread in the environment due to negligence. The pesticides can be spilled, spread in unsuitable places or in incorrect ways or the equipment can be cleaned in a careless way. Even a few millilitres of a pesticide spilled on the farmyard can cause large effect on the environment. Imagine that 1 gram of active substance is spilled on a farmyard made of gravel. To dilute the pollution to 0.1 µg/l (the EU limit for presence of single pesticide in water), 10 000 m^3 of water is needed (Fogelfors, 1995).

There are today many reports of occurrence of pesticides in surface and ground waters. As long as pesticides have been used there have been traces in the environment of these substances. The most common effect of pesticides is in other words a general pollution of the environment (Fogelfors, 1995). All substances that have an anthropogenic origin can be classified as environmental polluters. This does not necessarily mean that they are dangerous to human health or the environment. But the effect is very often not fully known.

Pesticides can have an influence on the soil, soil organisms and biological soil processes. In most cases these effects are marginal compared to other cropping measures or "natural" factors. Many pesticides can have damaging effects on water organisms. Some substances are accumulated in the sediment and can cause problems during long time ahead (Fogelfors, 1995).

For insects and game, the indirect effects of herbicide use are far more relevant that direct poisoning. The indirect effects can for example be the change of flora when herbicides are used (Fogelfors, 1995).

Pesticides are used to fight living organisms and can be dangerous to humans. For the farmers, the pesticides can be taken in through skin and lungs or by accidental swallowing. The damage on the body can be of different kinds, irritation, acute poisoning, allergies etc (Fogelfors, 1995). For the general public, the health risks of pesticides are small according to the National Food Administration (Livsmedelsverket, www). The residues in agricultural products are only a few percent of the maximum intake limit. In drinking water there are more uncertainties. There is no judgement of how many people in Sweden that are exposed to pesticides in drinking water. But the majority of the population is not exposed to dangerous levels of pesticides in drinking water according to the National Food Administration.

4 FARMING SYSTEMS

Before the LCA is carried out, the farming systems need to be defined. The chemical farming system is based upon a farm in Tierp, Sweden. Most conditions are the same in the mechanical scenario, such as fertilisers and other chemicals besides herbicides. The difference between the scenarios is mainly the weed control. As the farm in Tierp do not use mechanical weed control, that part of the study is solely based upon literature studies.

As mentioned earlier, in the LCA a mixture of what is appropriate in theory and what is actually done on the farm in Tierp will be used.

4.1 Crop sequence

4.1.1 Literature

In Sweden's climate, a good crop sequence is the base of a sustainable farming system. It is important for the outcome of the yield and affects the plant nutrition, soil humus content, fungus and insects. But it also affects the weeds (Fogelfors, 2001).

In order to carry out a realistic LCA it is vital that a proper crop sequence is determined. The crop sequence has to be similar in both the scenarios. This means that it has to be a sequence that is suitable for both chemical and mechanical weed controls. As it seems, the mechanical scenario is the most dependent on a suitable crop sequence and so will be the determining system and the chemical scenario will just follow that order. So how does one determine a proper crop sequence for mechanical weed control?

The first question that needs to be answered is how the crop sequence affects the weeds. According to several studies the chosen sequence is crucial for the amount and species of weeds appearing on the field (Fogelfors, 1995 p18; Gummesson, 1992 and Hammar, 1990). To keep control of the weeds it is important that the sequence contains both winter and spring crops. The weeds that prefer winter crops and weeds that prefer spring crops are alternately favoured and disfavoured, making it hard for them to establish any larger populations. But most important of all is that the sequence contains cultivated grassland, ley. By alternating annual and perennial crops it is possible to control both the annual and perennial weeds (Fogelfors, 2001).

What kind of weeds that appear are strongly related to the chosen crop. In literature relating to the subject following is said:

Spring cereal crops: Barley is the most competitive spring crop because of its ability to grow side shoots and it's well developed root system. Second best is oats and after that spring wheat (Fogelfors, 1995). Weeds that commonly appear in spring crops are *Aventa fatua* (wild oats), *Chenopodium album* (white pigweed), *Polygonum aviculare* (knotgrass), *Stellaria media* (chickweed), *Elymus repens* (couch grass), *Equisetum arvense* (common horsetail) and *Cirsium arvense* (field thistle) (Fogelfors, 2001).

Winter cereal crops: Winter rye is labelled as the most competitive winter crop, due to its quick growth and its long straws. Rye seldom gives any problems with weeds. Second best is rye wheat followed by winter barley and winter wheat (Lundkvist & Fogelfors, 1999). Common weeds in winter crop are *Polygonum aviculare* (knotgrass), *Matricaria Perforata Merat* (scentless mayweed), *Galium aparine* (goose grass), *Chamomilla recutita* (camomile), *Stellaria media* (chickweed), *Galeopsis* (hemp nettle), *Centaurea cyanus* (cornflower), *Myosotis arvensis* (forget-me-not), *Elymus repens* (couch grass) and *Apera spicaventi* (silky bent grass). (Fogelfors, 2001)

Potato: In the beginning of the growth season potato is a very weak weed competitor. It is then of great importance that mechanical tillage is conducted to fight annual weeds. But by the time the potatoes bloom the weeds are very difficult to maintain (Fogelfors, 1995).

Ley: Cultivated grassland has in field experiments proven to be a very efficient weed controller. A crop sequence with ley has drastically fewer weeds than one without ley (Nilsson, 1992).

The ley efficiently fights field thistle and corn thistle, under the condition that it is thick and in good growth (Gummesson, 1992). These two weeds are the most difficult to control without herbicides and are very resistant to mechanical tillage. Therefore it seems imperative to include ley in the crop sequence.

Ley has also an inhibiting effect on the production of weed seeds and on the period of time the seeds are viable. (Gummesson, 1992).

On the other hand, ley favours weeds such as *Plantago major* (broad-leafed plantain), *Ranuculus repens* (creeping buttercup), and *Taraxacum vulgare* (dandelion) (Fogelfors, 2001).

Peas: Peas are not good competitors and can cause severe weed problems if appropriate weed control is not carried out. Weeds in peas very often cause harvest problems, particularly during rainy autumns. The peas lodge at an early state and can then be fully overgrown by weeds (Gummesson, 1992).

4.1.2 Chosen crop sequence

Based on above knowledge the following crop sequence for both the chemical and the mechanical system is chosen as basis for the LCA-study:

- Barley + under seed
- Ley I
- Ley II
- Winter Wheat
- Oats
- Potatoes

4.2 Presentation of Fäcklinge Fors Farm

Fäcklinge Fors farm is situated in Tierp in the province of Uppland in Sweden. Lars-Gunnar Sandin runs the farm. It includes 180 hectare of grown field and about 30 cows on extensive pasture. The soils are quite light, varying from loam to fine sand soil. The phosphorus storage is mainly in class III and IV, the potassium in class II and III.

In the LCA the soil is presumed to be sandy loam in P-AL class III and K-AL class II.

On the farm in Tierp barley, winter wheat, oats, potato and ley is grown in accordance with the earlier chosen crop sequence. The ley is harvested as both hay and silage, but in the LCA all ley is presumed to be harvested as silage.

Some of the straw is harvested on Fäcklinge Fors farm, but in this study all straw is assumed to be incorporated in the soil. This means that no allocation has to be done between the crops and the straw.

According to the farmer, the weeds that cause most problems on Fäcklinge Fors farm are *Chenopodium* (goosefoot), *Elymus repens* (couch grass), *Lamium* (dead nettle), *Polygonum aviculare* (knotgrass) and *Galium aparine* (goose grass).

4.3 Yields

4.3.1 Fäcklinge Fors

The yield varies very much from year to year. As an average barley and oats gives rise to about 4 ton/ha, winter wheat 5-6 ton/ha, ley 5-6 ton/ha and potatoes approximately 25-30 ton/ha.

4.3.2 Literature

The normal yield for conventional farming in the province of Uppland is presented in Table 1. Note that these yields will be used in the LCA and so represents the functional unit: the total harvest from all crops during one crop sequence.

Table 1. Normal yields Uppland (Jordbruksverket, 2002). The yields are given as 15% water content for cereals and as dry weight for ley

Crop	Yield (kg/ha)
Barley	4 436
Ley, total	6 586 [1]
Winter wheat	5 657
Oats	4 021
Potato	22 212

1. From Agriwise (www). First harvest 4 128 kg, second harvest 2 458 kg.

In the mechanical scenario the yields will probably be lower than in the chemical scenario. This is interesting because the functional unit is the total yield. So if the mechanical scenario gives rise to lower yields, a larger area of land will have to be cultivated to reach the same yield. This means more use of fossil fuels and other environmental effects.

What yield that can be estimated in the mechanical scenario depends on a number of different factors. First of all, how and when the mechanical weed control is carried out. For example, harrowing usually has best effect on weeds in an early state, but if you harrow too early the crop might be damaged. The time of treatment is a very important factor. An evaluation between the effect on the weeds and the damage on the crops has to be done. Other things that affect the outcome of the yield with mechanical weed control are types of crop, type of weeds, variations in weather, seedbed preparations etc (Tersbøl et al., 1998). Since it is necessary to put figures on the losses to fulfil the life cycle assessment, it is important to estimate a reasonable loss.

Between 1974 and 1988 a field trial was conducted in southern Sweden where mechanical and chemical weed control was compared to untreated field plots (Gummesson, 1990). The crop sequence consisted mainly of oats and barley, sometimes alternating with rye and wheat. The mechanical control consisted of harrowing. The results showed that the yields were lower in the mechanical plots than in the chemically treated as well as the untreated. The losses in mechanically treated fields were approximately 400 kg/ha in winter wheat, 420 kg/ha in barley and 450 kg/ha in oats as an average over the years.

In other field experiments losses between 4-20 % has been noticed in oats and 7-40% losses in barley (Boström, 1999). These trials were also conducted with a very monotone crop sequence.

In 2002 The Swedish Board of Agriculture published a report, a plan of action, for the usage of pesticides in Sweden (Emmerman et al., 2002). They estimated the losses in cereals to 250-500 kg/ha as a consequence of larger number of weeds when pesticides are no longer used. For potatoes the losses were valued to 4 000 kg/ha. However, these estimations are based on a short time perspective and when no other weed control (direct or indirect) is applied. It is the loss that you can expect if you keep growing the same crops year after year and just stop using pesticides.

These results show how difficult it is to switch to mechanical weed control in a crop sequence with only cereals. In this paper though, more effort is put on indirect weed control and the losses are not likely to be of the same magnitude.

In Denmark a lot of research has been done on what losses to expect when herbicides are not used. In a report by Tersbøl et al. (1998) the estimated loss in spring crops is 0-15 % for mechanical weed control compared to chemical. In winter crops the same figure is 0-10 %. In potato cropping the same yield can be obtained with mechanical weed control as with chemical.

In another Danish report (Mikkelsen et al., 1998) the losses when transferring from chemical to mechanical weed control are 11-16 % in winter wheat and 6-15 % in barley.

The Danish government has decided to minimise the usage of chemicals in agriculture. A very comprehensive investigation, the Bichel-study, was conducted. In this report (Bichel-udvalget, www) approximations of losses as a consequence of switching to mechanical weed control are declared. In winter wheat the losses are estimated to 13%, in barley 8 %, in potatoes 0 % and in oats 9 %. These figures are based on a few Danish trials, but mostly upon expertise judgement.

For ley the decrease in yield are probably not of any larger significance. Emmerman et al. (2002) calculates that the yield is lowered by 3% if all chemical treatment is ceased. In field trials it has been proven that there is no difference in yields from ley in farming systems with chemical and mechanical weed control (Fischer and Hallgren, 1991).

In this study it is estimated that the yields in the mechanical system is lowered by 10 % in barley, 0% in ley, 12% in winter wheat, 10% in oats and 0% in potatoes.

4.3.3 Chosen yields

The chosen yields in the chemical and mechanical scenarios as well as the used area of land are presented in Table 2. Note that the yields in the table also represent the functional unit.

Table 2. Yields and used land

	Chemical scenario			Mechanical scenario		
	Yield (kg/ha)	Land use (ha)	Yield total (kg)	Yield (kg/ha)	Land use (ha)	Yield total (kg)
Barley	4 436	1	4 436	3 992	1.11	4 436
Ley I	6 586	1	6 586	6 586	1	6 586
Ley II	6 586	1	6 586	6 586	1	6 586
Winter wheat	5 657	1	5 657	4 978	1.14	5 657
Oats	4 021	1	4 021	3 619	1.11	4 021
Potato	22 212	1	22 212	22 212	1	22 212
Sum (functional unit)		**6**	**49 498**		**6.36**	**49 498**

4.4 Fertilisers

The needed rate of fertilisers is strongly related to the yield. The yields in the mechanical scenario are lower per hectare and subsequently the needed amount of fertilisers per hectare.

4.4.1 Fäcklinge Fors

The fields on Fäcklinge Fors farm do not have any larger storage of potassium or phosphorus and continuously needs to be fertilised. On most cereal fields, the commercial fertiliser NPK 24-4-5 is used. In winter wheat additional nitrogen is also added; Axan (NS 27-3).

In potato (King Edward) the commercial fertiliser NPK 8-5-19 is applied.

In ley, fertilisers are spread in two rounds. The first time NPK 24-4-5 is applied and the second time Axan is spread.

4.4.2 Literature

Jordbruksverket, the Swedish board of agriculture gives the following recommendations for nitrogen fertilisation:

Table 3. Recommended amount of nitrogen fertilisers, kg/ha (Jordbruksverket, 2002)

Crop	Yield (ton/ha)					
	4	5	6	7	8	9
Barley, oats	70	90	110	130	-	-
Ley (2 harvests)	-	-	135	155	175	-
Winter wheat	-	115	135	155	175	195
	Yield (ton/ha)					
	25	30	35	40		
Potato (King Edward)	80	90	110	130		

For phosphorus and potassium the recommendations are based upon in which P-AL and K-AL classes the soil is placed. Jordbruksverket (2002) gives the following recommendations for P-AL class III and K-AL class II:

Table 4. Recommended amount of phosphorus and potassium

Crop	Yields (ton/ha)	P (kg/ha)	K (kg/ha)
Cereals	5	15	45 [2]
Ley I	6	15	90
Ley II	6	15	140
Potato	30	60[1]	160

1. Sufficient for the two following crops
2. If straw is removed the dose is raised by 20 kg K/ha

The amount of P- and K-fertilisers are adjusted to the yield by adding or subtracting 3 kg phosphorus and 5 kg potassium per ton divergent cereal, 0.5 kg phosphorus and 4 kg potassium per ton potato and 20 kg potassium per ton divergent ley.

4.2.3 Chosen fertilisers

In Table 5 the chosen amount of fertilisers per hectare is shown. These are the data that will be used in the calculations of the LCA. The fertilisers are chosen solely on basis of the recommendations in the literature review.

Table 5. Chosen fertiliser strategy per hectare. Since the yields are lower in the mechanical scenario, the amounts of fertilisers are lower per hectare

	Chemical scenario			Mechanical scenario		
	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Barley	79	13	42	70	12	40
Ley I	145	17	93	145	17	93
Ley II	145	17	143	145	17	143
Winter wheat	128	17	48	115	15	45
Oats	70	12	40	62	11	38
Potato	80	56	130	80	56	130

4.5 Seed

4.5.1 Fäcklinge Fors

The following varieties are used:

Table 6. Varieties on Fäcklinge Fors Farm

Crop	Variety
Barley	Cecilia and Baronesse
Ley	SW 944
Winter wheat	Kosack
Oats	Sang
Potato	King Edward and Bintje

4.5.2 Literature

The suitable amounts of seed are according to Odal listed in Table 7 (Andersson, 2001). Odal is a Swedish farmer owned cooperation which mainly deals with cereals.

Table 7. Amount of seed

Crop	Seed (kg/ha)
Barley (two-row)	180
Ley	20-25
Winter wheat	210
Oats	205
Potato	2 200-3 700

4.5.3 Chosen amount of seed

The procedure for sowing is the same in the chemical and the mechanical scenario for all crops except ley. In the chemical scenario the ley seeds are sown just after the barley. In the mechanical scenario though, the sowing of ley is postponed. The sowing is instead done in connection with a weed harrowing before the emergence of the crop. The chosen amount of seed is in accordance with Table 7; ley is assumed 20 kg and potato 2 750 kg.

4.6 Tillage operations

The aim of tillage operations is to prepare the soil for a certain crop. The tillage operations are the same in both the chemical and the mechanical scenario. Some of these operations also have an effect on weeds and could just as well have been included in the weed control chapters. But since the operations are the same in both the scenarios there is a point in treating them together.

4.6.1 Literature

Ploughing. In the autumn there is a need to loosen the soil after the compacting during summer. Crop residues are buried; down under the soil the organic substances are faster metabolised. Ploughing is also effective in fighting perennial weeds. The plough cuts off the roots and under-ground stems of the weeds and turns the soil over.

Seedbed preparation. Before sowing the soil has to be prepared. The wanted result from seedbed preparation is

- a smooth soil surface
- small soil particles
- sorted soil; the finest particles closest to the seedbed bottom
- the right sow depth
- a smooth seedbed bottom
- weed control

This can be done with different types of harrows, levelling boards, cage rollers and disc tools.

Ridging. Ridging is mainly done in potato cropping to cover the potatoes and protect them from sunlight. Also, annual and perennial weeds are fought. An amount of soil is moved to cover the potatoes and at the same time weeds are pulled up or covered by soil.

Stubble cultivation. Stubble cultivation is done in both the chemical and mechanical scenario when the ley is terminated. It is necessary to stubble cultivate in order to cut the plant residues and mix them properly with the soil before the winter wheat is sowed.

4.7 Pesticides

4.7.1 Fäcklinge Fors

The following pesticides are used on the farm: Tilt Top 500 EC (fungicide), Stereo 312.5 EC (fungicide), Sumi-Alpha 5 FW (insecticide), Epok 600 EC (against downy mildew), Shirlan (against downy mildew) and Reglone (haulm killer). The dose is regulated by need, an evaluation done by the farmer on site.

4.7.2 Literature

As the types of pesticides used on Fäcklinge Fors farm can be considered as quite representative for a conventional Swedish farm, these data will be used (Andersson, 2001). The rate of the pesticides will on the other hand be determined from literature, Agriwise (www) and Anderson, 2001. The normal rates of the above pesticides are presented in Table 8.

4.7.3 Chosen pesticides

The time perspective in this LCA is one year. But some consideration has to be made for the longer time perspective. For instant, some pesticides are not used on every field every year; reducing the number of occasions to less than one represents this. For example, if the number of occasions is 0.3 the pesticide is used every third year.

Table 8. Crop, pesticide and dose per hectare

Crop	Product	Number of occasions x dose (l)	Active substance	Active substance (g/ha)
Barley	Sumi-Alpha 5 FW	0.3 x 0.3	Esfenvalerat	45
	Stereo 312.5 EC	0.3 x 1.0	Cyprodynil + propikonazol	94
Ley	-	-		
Winter wheat	Sumi-Alpha 5 FW	0.3 x 0.3	Esfenvalerat	45
	Tilt Top 500 EC	1 x 0.8	Propikonazol + fenpropimorf	400
Oats	Sumi-Alpha 5 FW	0.3 x 0.3	Esfenvalerat	45
	Tilt Top 500 EC	0.2 x 0.8	Propikonazol + fenpropimorf	80
Potato	Sumi-Alpha 5 FW	0.3 x 0.3	Esfenvalerat	45
	Shirlan	5 x 0.35	Fluazinam	875
	Reglone	2 x 3	Dikvat	1200
	Epok 600 EC	2 x 0.45	Mefenoxam + fluazinam	540

4.8 Chemical weed control

4.8.1 Fäcklinge Fors

On Fäcklinge the following chemicals are used for weed control: Harmony Plus 50 T, Express 50 T, Ariane S, Starane 180. Hormotex 750. Sencor, Titus 25 DF and Roundup.

4.8.2 Literature

As the types of herbicides used on Fäcklinge Fors farm are quite representative, these data will be used. But the rate of the herbicides will be determined by studying literature. The normal rates for the above herbicides are presented in Table 9 (Agriwise, www; Anderson, 2001).

4.8.3 Chosen chemical weed control

In Table 9 the chosen herbicides and doses are presented.

Table 9. Crop, herbicide and dose per hectare

Crop	Product	Dose	Active substance	Active substance (g/ha)
Barley + underseed	Express 50 T	1.5 tablets	Tribenuronmetyl	6
	Hormotex 750	0.5 litres	MCPA	375
Ley	Roundup Bio	3.5 litres	Glyfosat	1260
Winter wheat	Harmony Plus 50 T	2.6 tablets	Tribenuronmetyl + Tifensulfuronmetyl	11
	Starane 180	0.6 litres	Fluroxypyr	108
Oats	Ariane S	2.0 litres	Klopyralid + MCPA + fluroxypyr	520
Potato	Sencor	0.4 kg	Metribuzin	280
	Titus 25 DF	50 g	Rimsulfuron	12

4.9 Mechanical weed control

4.9.1 Literature

The most important tool to fight weeds is the indirect measures taken in the farming system. But it is also important to fight the weeds directly in order to ensure that the existing weeds do not multiply. The following direct mechanical weed control is common:

Stubble cultivation. By stubble cultivating with disc tools, cultivator or alike as soon as possible after harvest perennials can be fought, mainly couch grass and other vegetative propagated weeds. The effect on annual weeds is limited. The best effect is reached if the tillage is repeated after a few weeks and followed by ploughing (Fogelfors, 1995).

Weed harrowing. There are mainly three types of weed harrowing (Lundkvist and Fogelfors, 1999):

- Blind harrowing. Blind harrowing means that you harrow after sowing but before the emergence of the crop.
- Harrowing after the emergence of the crop. This should not be done when the crop has just emerged (1-2- leaf-stage) but rather in 3-leaf-stage.
- Selective harrowing. Selective harrowing is conducted with a long-tine harrow in crops that grow in dense rows, for example when the cereal starts its stem elongation.

Harrowing fights weeds by tilling the top layer of soil. Weeds are most sensitive to harrowing in their early stages as soil covers them. Generally annual weeds like *Chamomilla recutita* (camomile), *Papaver* (poppy) and *Vioala arvensis* (field pansy) are sensitive to harrowing, while it has little effect on perennials. Weeds usually germinate and establish under longer periods than the crops. It is therefore sometimes advisable to harrow several times to reach good effects against weeds (Fogelfors, 1995). How many times the harrowing should be conducted depend on type of soil and the current weed-pressure. Tersbøl et al. (1998) recommends in spring cereal crops with high weed-pressure, one blind harrowing and 1-2 harrowings after the emergence of the crop. In winter crops they recommend one blind harrowing and 2-3 selective harrowing.

The timing of the weed harrowing is crucial for the result. The difference in size between the crop and the weed has to be optimal. The harrowing should take place when the weed is as small as possible, but the crop has to be large enough not to take to much damage. When this time occurs depends on amount and composition of weeds, type of crop, soil and climate (Mattsson and Sandström, 1994).

In spring crops it is possible to wait with the sowing of under-seed ley. This gives the opportunity to weed harrow one time in connection to the sowing of the ley-seed.

In potatoes the weed harrowing and the ridging is done together in one instant.

Inter-row hoeing. Inter-row hoeing chops off the weeds and at the same time loosen the soil. The weeds are fought by cutting off the roots, being covered by soil or by being pulled up. Inter-row hoeing is gentler to the crop than harrowing. Inter-row hoeing can be done in crops that are planted with large distances between the rows, such as sugar beets, potatoes and vegetables. It can also be done in cereals, but only if the distance between the rows are large enough, at least 17-20 cm, which is rather unusual. Inter-row hoeing is best done while the weeds are small, but the timing is not so important as in harrowing (Lundkvist and Fogelfors, 1999).

Mowing. Weeds can also be cut of with a mower. This is common in organic farming systems where field thistle is a problem weed. By cutting of the thistle it is restrained from propagating (Bovin, www).

4.9.2 Chosen mechanical weed control

As mentioned earlier, weed control in a farming system consists of both direct and indirect actions. In Table 10 the direct weed control that differs from the chemical scenario is listed. This weed control strategy is put forward in co-operation with Maria Wivstad (pers. com).

Table 10. Mechanical weed control for a crop sequence

Crop	Mechanical weed control
Barley	1 x weed harrowing
Ley I	-
Ley II	1 x stubble cultivation
Winter wheat	-
Oats	2 x weed harrowing
	2 x stubble cultivation
Potato	2 x weed harrowing

4.10 Summary of chosen farming systems

A summary of the determined farming systems is presented in Table 11 and 12.

Table 11. Summary of chosen conventional farming system

	Yield (kg/ha)	Fertilisers (kg/ha N-P-K)	Seed (kg/ha)	Tillage	Insect and fungus control (l/ha)		Chemical weed control (l/ha)	
Barley + underseed	4 440	79-13-42	180	1 x ploughing 3 x harrowing	Stereo Sumi-Alpha	0.3 0.09	Harmony Plus Starane 180	1.5 tablet 0.4
Ley I	6 590	145-17-93	20	-	-		-	
Ley II	6 590	145-17-143	-	1 x stubble cultivation	-		Roundup Bio	3.5
Winter wheat	5 660	128-17-48	210	1 x ploughing 3 x harrowing	Tilt Top Sumi-Alpha	0.8 0.09	Ariane S Hormotex 750	3.0 2.0
Oats	4 020	70-12-40	205	1 x ploughing 3 x harrowing	Tilt Top Sumi-Alpha	0.16 0.09	Ariane S	2.0
Potatoes (King Edward)	22 210	80-56-130	2 750	1 x ploughing 2 x deep cultivation 2 x ridging	Shirlan Epok Reglone Sumi-Alpha	1.75 0.90 6.0 0.09	Sencor Titus	0.4 50 g

Table 12. Summary of chosen mechanical farming system

	Yield (kg/ha)	Land use (ha)	Fertilisers (kg/ha N-P-K)	Seed (kg/ha)	Tillage	Insect and fungus control (l/ha)		Mechanical weed control
Barley + underseed	3 990	1.11	70-12-40	180	1 x ploughing 3 x harrowing	Stereo Sumi-Alpha	0.3 0.09	1 x weed harrowing + sowing of ley
Ley I	6 590	1	145-17-93	20	-	-		-
Ley II	6 590	1	145-17-143	-	1 x stubble cultivation	-		1 x stubble cultivation
Winter wheat	4 980	1.14	115-15-45	210	1 x ploughing 3 x harrowing	Tilt Top Sumi-Alpha	0.8 0.09	-
Oats	3 620	1.11	62-11-38	205	1 x ploughing 3 x harrowing	Tilt Top Sumi-Alpha	0.16 0.09	2 x weed harrowing 2 x stubble cultivation
Potatoes (King Edward)	22 210	1	80-56-130	2 750	1 x ploughing 2 x deep cultivation 2 x ridging	Shirlan Epok Reglone Sumi-Alpha	1.75 0.90 6.0 0.09	2 x weed harrowing in connection with ridging

5 INVENTORY OF FARMING SYSTEMS

In this chapter data will be gathered and presented. A concluding datasheet for the emissions of each crop is presented in Appendix 7-17.

5.1 Field operations

Data for fuel consumption and emissions when performing field operations are taken from JTI, the Swedish Institute for Agricultural and Environmental Engineering, a report by Lindgren et al. (2002), see Appendix 2. The data is collected from a Valtra 6600 tractor on heavy clay. The soils at the studied farm is of a lighter kind and operations like ploughing should give rise to a little lower fuel consumption, but since such data is not available these are the figures that will be used.

The JTI-report does not cover emissions of SOx. These emissions are instead based on content of sulphur in the fuel. According to Hansson and Mattsson (1999) the emissions can be estimated to 0.0935g SO_2/MJ.

There are no measurements of fuel consumption for spraying in the report from JTI. According to Hansson and Mattsson (1999) the load at spraying can be assumed to be equivalent to the load at sowing.

The ley is harvested as silage with a mower conditioner. The grass is pressed to round bales and then coated with stretch film. There are no figures on how many hectares per hour a stretch film device can do in the JTI-report but the emissions per hour is given (Lindgren et al., 2002). According to Magnus Lindgren (pers. com.) the average speed can be estimated to 5 km/h for such operations and the working width the same as for the mower conditioner.

For potato cropping, figures from Mattsson et al. (2002) has been used for fuel consumption in field operations (Appendix 2). The emissions on the other hand were calculated from Lindgren et al. (2002) for operations that are similar, for example were potato-planting set equal as stubble cultivation.

Transports to and from fields to farm are calculated by adding 10% of field operations.

5.2 Diesel production

The production and distribution of diesel are accounted for in this LCA. Figures are taken from Uppenberg et.al. (2001) and are presented in Appendix 3.

5.3 Electricity production

Data for production of electricity are taken from Uppenberg et al. (2001) and are presented in Appendix 3. The data is based on average Swedish electricity during 1999. produced by 48.2 % hydropower and 44.3 % nuclear power.

5.5 Pesticide and herbicide production

There are very scarce data on energy use and emissions from pesticide production. In this study, figures from Kaltschmitt & Reinhardt (1997) were used. The data are given as emissions per kilogram active substance, not regarding type of substance (Appendix 4).

5.4 Mineral fertiliser production

Producing mineral fertilisers requires energy. Especially the production of nitrogen fertilisers requires large amounts of energy, mostly carried by natural gas. A number of substances are also emitted to air and water in the processes of making mineral fertilisers. Davis & Haglund (1999) have investigated this, see Appendix 5. The fertilisers are assumed to be manufactured in Köping, Sweden. The distance between Köping and Tierp is 175 kilometres and the fertilisers are transported by truck. The emissions from the transports are based on data from NTM, the Network for Transport and the Environment (www), presented in Appendix 5.

5.6 Seed production

For cereals as well as potatoes, the production of seed does not differ substantially from ordinary cultivation. In this study, the figures from cereal production that already has been calculated will be used. Seeds in barley, winter wheat, oats and potato will be net calculated and increased by 10% to compensate for higher cultivation costs in seed production. For cereal seed production 10 % is commonly used (Cederberg, 1998).

The production of ley seed differs significantly from cultivation of ley for silage. The production of grass and clover was thoroughly investigated by Cederberg (1998) and calculations in this study are based on those data.

5.7 Production of stretch film

The harvested ley is pressed to round bales and then covered with plastic stretch film. The use of stretch film is estimated to 4.3 g per kg dry substance of ley by JTI (Dalemo et al., 1997). The stretch film is assumed to be produced of LDPE (low density polyethylene). Data for production and handling of waste (to landfill) for LDPE are taken from Tillman el al. (1991) and are presented in Appendix 6.

5.8 Emissions of N in cropping

In agricultural production, emissions of ammonia (NH_3), nitrous oxide (N_2O) and nitrate (NO_3^-) can have large influence on acidification, eutrophication and the atmosphere's radiate balance. It is therefore of great importance that these emissions are correctly calculated. Unfortunately, accurate data is hard to obtain since the sizes of the emissions are strongly influenced by climate, type of soil and fertilisers and how the fertilisers (manure) are handled (Cederberg, 1998).

5.8.1 Nitrate (NO_3-N)

Dissolved nitrogen easily follows the water movement trough the soil. Leaching of NO_3^- occurs when surplus water is drained away, mainly during winter season. The climate has a large influence on the N-leaching. The amount of precipitation and the temperature during autumn determines the amount lost N. The type of soil can also have influence on the N-leaching; lighter soils are more inclined to leach than clay soils (STANK).

Further, there is a connection between tillage and N-losses. When the soil is cultivated large soil aggregates are crushed to smaller pieces. This means that the microorganisms in the soil get a larger active surface to work on. Also, air and warmth is baked in to the soil. Theses two factors together lead to a larger mineralization and a larger risk of leaching (STANK).

The N-leaching is in this study calculated in accordance with the STANK-model by the formula:

N-leaching = basic leaching x crop factor x cultivation factor + manure effect + effect of fertilising intensity

The basic leaching is determined by geographic location, precipitation and soil type. The crop factor is determined by type of crop. Crops like potato and peas have a high factor since they are more inclined to leach due to the sparse growing. The cultivation factor is set to adjust for the difference between early and late autumn tillage. An early tillage gives a higher factor. The effect of spreading manure is determined by geographic location, type of soil and crop. The effect of fertilising intensity accounts for the increase in N-leaching when the amount of applied fertilisers is larger than the recommended amounts.

5.8.2 Ammonia (NH_3)

Losses of ammonia in agricultural production mainly occur while spreading manure. NH_3 emissions from mineral fertilisers are generally small, depending on the pH of the soil. Tidåker (2003) points out that the figure varies between 0.2% and 1% in different studies. In this study the average figure 0.6% of applied mineral fertilisers is used.

5.8.3 Nitrous oxide (N_2O)

Emissions of nitrous oxide occur from natural processes in the conversion of nitrogen. Nitrous oxide is also emitted from agricultural land when fertilisers are added to the soil. As N_2O has a very high global warming potential (296 CO_2-equivalents) it will have an impact on the result of global warming. The loss of N2O from the soil is calculated in accordance with the IPPC guidelines; 1.25% of total added nitrogen is emitted as N_2O-N (IPPC, 1997).

Further, there are also indirect emissions of N_2O. Emissions of nitrate and ammonia go through the nitrogen cycle and hereby production of N_2O will occur. According to IPPC (1997) these indirect emissions can be calculated by adding 0.01 kg N_2O per kg NH_3 and 0.025 kg N_2O per kg NO_3^-.

In Table 13 a summary of the N emissions is presented.

Table 13. Emissions of N from field for chemical scenario. Numbers in parenthesis are for the mechanical scenario when differing between the scenarios

	Applied amount of nitrogen fertiliser (kg/ha)	NO_3^- (g/ha)	NH_3 (g/ha)	N_2O (g/ha)	N_2O indirect (g/ha)
Barley	80 (72)	10 500	480 (432)	1 000 (900)	267
Ley I	145	8 750	870	1 813	227
Ley II	105	26 250	630	1 313	663
Winter wheat	130 (114)	17 500	780 (686)	1 625 (1 425)	445
Oats	70 (63)	17 500	420 (378)	875 (788)	442
Potato	80	29 750	480	1 000	749

5.9 Losses of phosphorus

Välimaa & Stadig (1998) have made a thorough literature review of phosphorus losses from field. It is here stated that the losses of P are very difficult to estimate. The size of the losses strongly depends on local conditions such as composition and pH of soil, amount of wind erosion, drainage and surface water. Losses also depend on type of farming system. The phosphorus losses can vary between 0.01 to 1.8 kg/ha (Välimaa & Stadig, 1998).

In the mechanical scenario, more tillage is done on the soil. According to Ulén (1997) the relationship between farming method and phosphorus losses is not established. A farming system without ploughing can for example lead to both increased and decreased phosphorus losses. Välimaa & Stadig (1998) proposes that 0.22 kg/ha is used for lighter soils in the plain districts in Svealand and that is used in this study for both scenarios.

6 IMPACT ASSESSMENT

The terminology used in this chapter is "chemical" for the scenario with chemical weed control system and "mechanical" for the scenario with mechanical weed control. The impact categories are presented in MJ, kilogram and mole equivalents, although not always per functional unit (FU).

6.1 Energy

The use of energy was divided into three categories: diesel, electricity and total (Figure 4). The category total includes diesel and electricity and all other sorts of energy used, for example natural gas. When calculating total energy, primary energy is used for electricity and diesel. 1 MJ of electricity corresponds to 2.05 MJ primary energy (Arnäs et al., 1997). In other words: the production of 1 MJ of electricity requires 2.05 MJ of energy. For diesel the factor is 1.06 (Uppenberg et al., 2001).

In the chemical scenario 18 040 MJ (511 l) of diesel was used. In the mechanical scenario the corresponding figure is 20 770 MJ (588 l). In total primary energy, the mechanical scenario uses about 4% more than the chemical scenario.

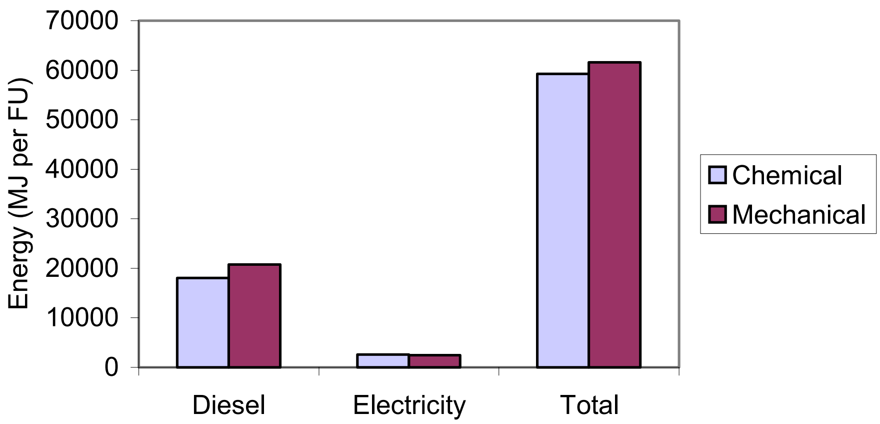

Figure 4. Energy usage for the chemical weed control scenario and the mechanical weed control scenario. Total energy is expressed as primary energy.

Oats has the largest difference between the chemical and mechanical scenario (Figure 5). In oats stubble cultivation is done twice in the mechanical scenario, which have a significant impact on the result. The mechanical scenario also occupies a larger area of land, which in turn means more exhaust gases from the tractor. Earlier in this study it was said that in order to discover the differences between the scenarios, it is important to look at a whole crop sequence. Nevertheless, it can be of interest to divide the environmental burden between the crops in order to facilitate the interpretation of the results.

The most energy demanding activity in potato cropping are the many field operations and the production of fertilisers. The potato is the only crop that shows a larger energy use in the chemical scenario due to herbicide production.

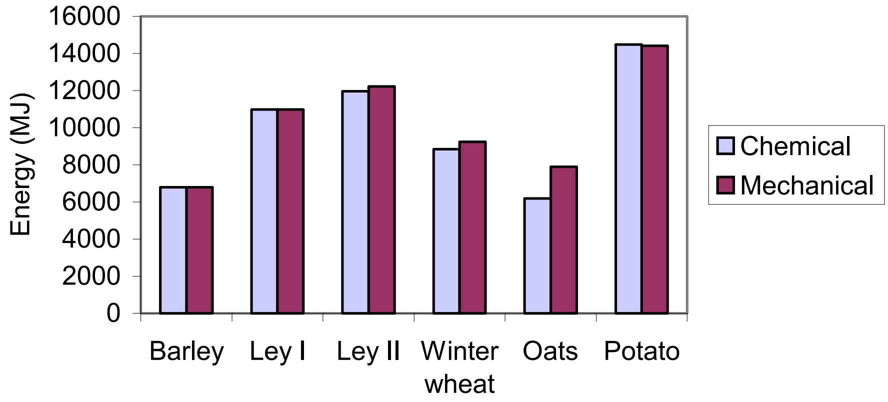

Figure 5. Primary energy use per crop in the chemical and mechanical scenario.

As Figure 6 indicates, the fertiliser production contributes most to the energy use. The production of pesticides is lower in the mechanical scenario as expected, but the difference is very small. In the category “other inputs” the following is included: seed production, electricity production, diesel production, stretch film production and transports to and from field.

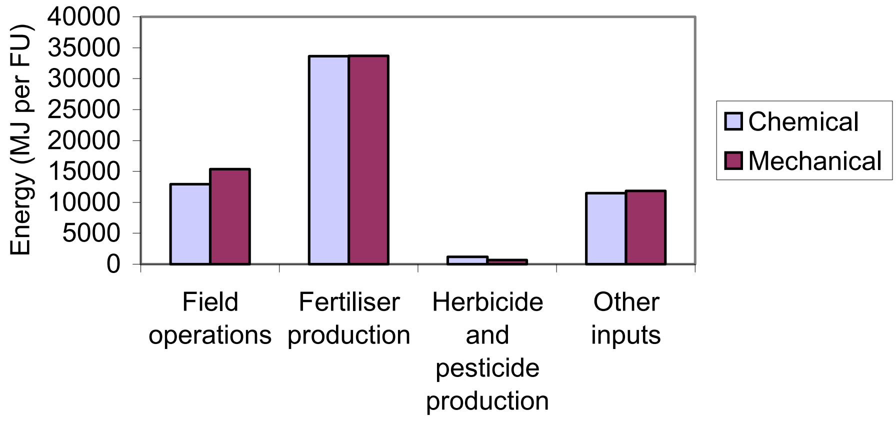

Figure 6. Total primary energy use divided by different activities.

6.2 Global Warming

In total, the contribution to GWP is only slightly larger in the mechanical scenario than in the chemical (Figure 7). The main contribution to global warming comes from nitrous oxide (N_2O). Nitrous oxide is mainly emitted from the soil, closely followed by emissions from production of mineral fertiliser. The largest contributors to CO_2 are fertiliser production and field operations.

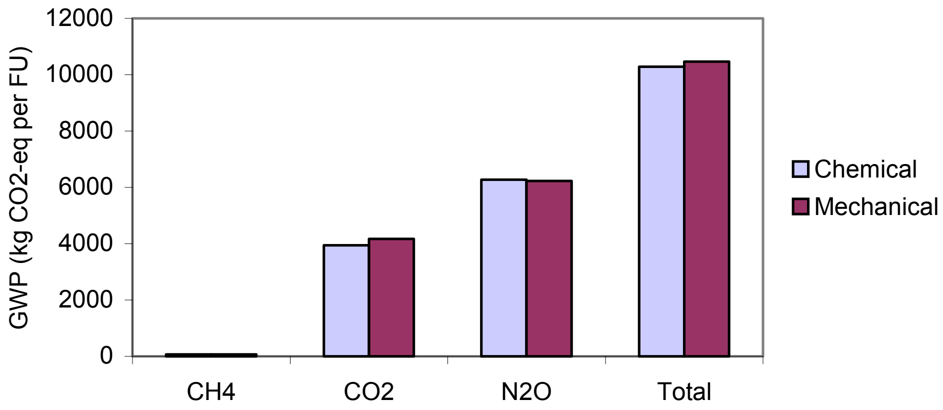

Figure 7. Substances in global warming potential per functional unit in the chemical and mechanical scenario.

As Figure 8 indicates, the production of mineral fertiliser has a large influence on the global warming. The emissions from soil are also of importance. These emissions are related to the applied amount of mineral fertilisers and so it can be stated that the largest contributing factor to global warming in these farming systems originate from the production and spreading of mineral fertilisers.

In the category other inputs the following is included: seed production, electricity production, diesel production, stretch film production, production of pesticides and herbicides and transports to and from field.

The mechanical scenario has a slightly larger contribution to global warming than the chemical scenario in the category field operations. This is due to the fact that the yields are smaller. The cultivated land is subsequently larger in order to adjust to the functional unit.

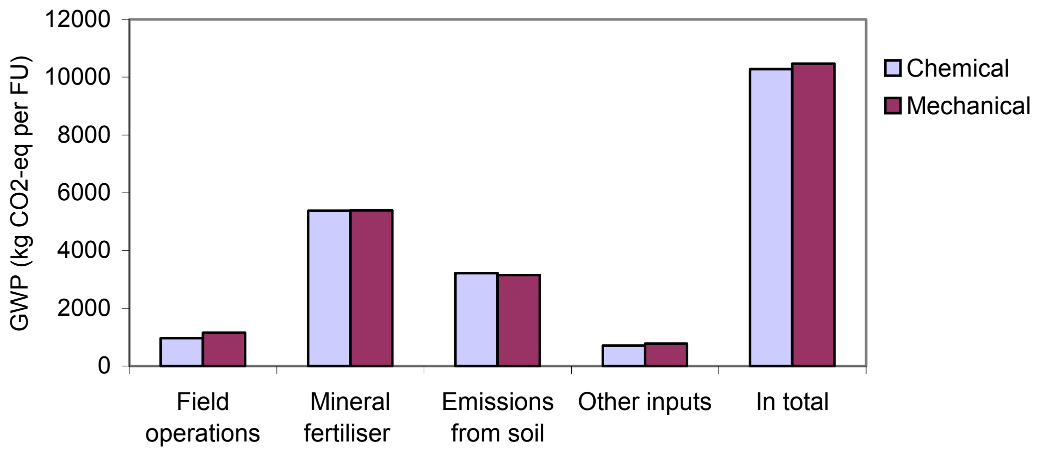

Figure 8. Contribution to global warming potential from different activities in the two scenarios per functional unit.

In Figure 9 the difference in contribution to global warming between the crops are shown. Oats display the largest divergence between chemical and mechanical weed control. Again, this is because of the powerful mechanical weed control.

Although potato had the largest energy consumption, it does not have a high global warming potential compared to the other crops. The reason is that the potato cropping mainly emits CO_2. Carbon dioxide has the characterisation factor 1 and other substances like N_2O (characterisation factor 296) plays a larger role in global warming.

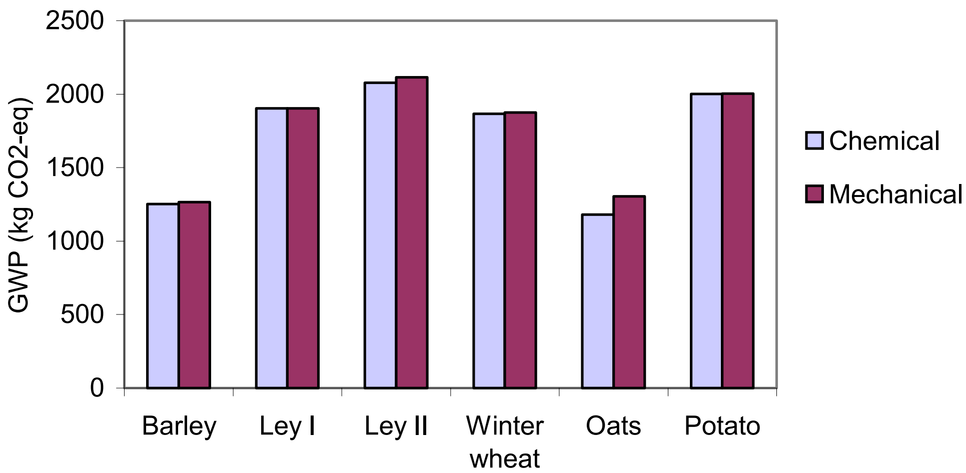

Figure 9. Contribution to global warming potential from the different crops in the two scenarios.

6.3 Eutrophication

In Figure 10 the different substances contributing to eutrophication is presented. The largest contributor is NO_3^-, which originates from nitrate leaching. The mechanical scenario gives slightly more emissions of NO_3^- since the arable land is larger.

The emissions of P originate from leaching and the emissions of NO_x from combustion of diesel in field operations.

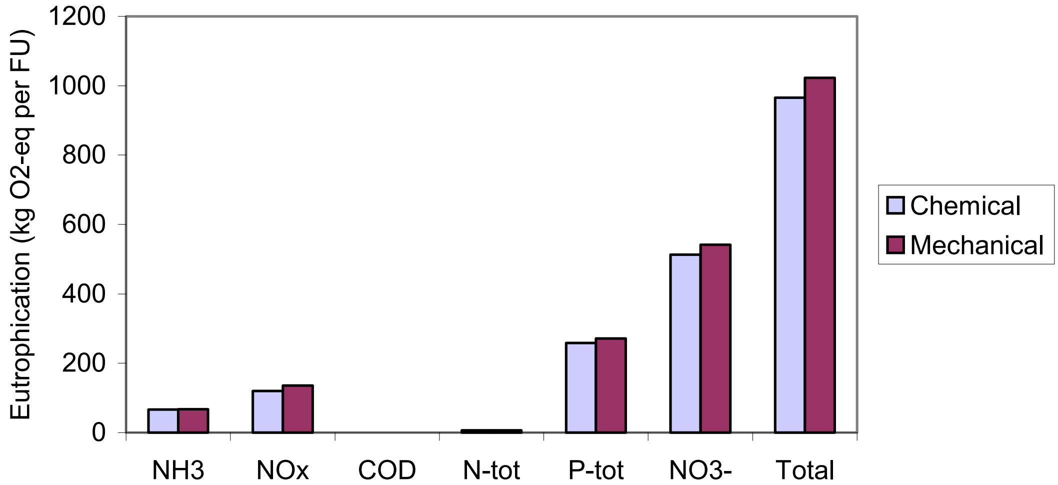

Figure 10. Substances contributing to eutrophication per functional unit for the two scenarios.

Potato cropping has the largest eutrophication effect in the farming systems (Figure 11). The explanation is that the potatoes require high amounts of phosphorus fertilisers that in the production phase contribute to eutrophication. Also, the nitrate leaching is high due to many tillage operations and the emissions of NO_x from field operations are larger than in the other crops.

Ley II has high eutrophication effect since the tillage when terminating the ley lead to increased levels of nitrate leaching according to the STANK model.

The largest diversion between the chemical and the mechanical farming system lies within cultivation of oats and winter wheat. This is because the emissions of P and NO_3^- from soil are larger in the mechanical scenario. Also, in oats the field operations are many more in the mechanical scenario and so the emissions of NO_x are larger.

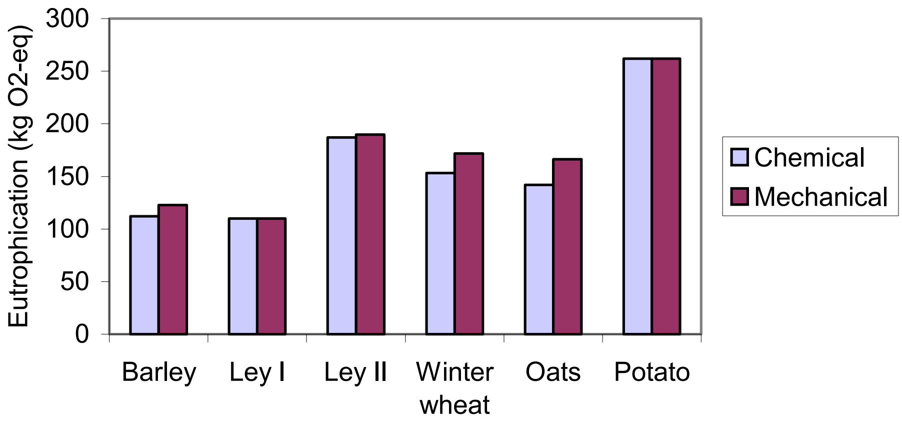

Figure 11. Contribution to eutrophication for different crops.

6.4 Acidification

As indicated by Figure 12. the most contributing substance to acidification is NO_x. The emissions of NO_x come from field operations and production of mineral fertilisers. The difference between the scenarios in NO_x is in other words related to the weed control.

The activity that leads to the emissions of SO_2 is fertiliser production, followed by field operations.

The NH_3 emissions mainly originate from soil emissions related to the applied amount of fertilisers.

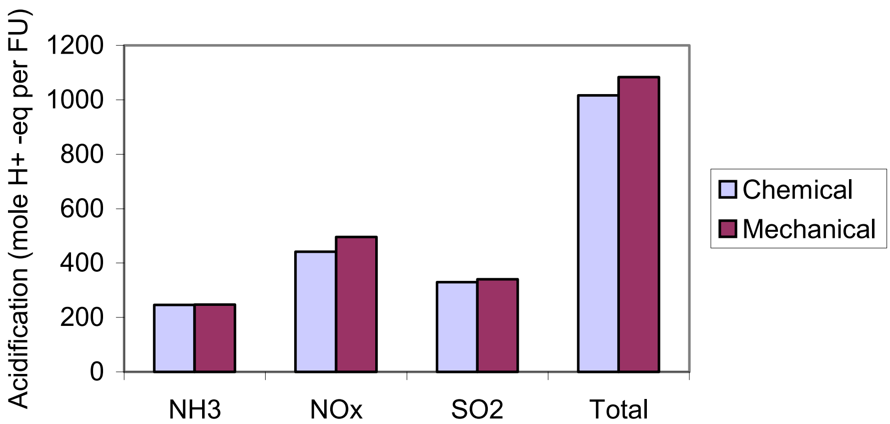

Figure 12. Contributions to acidification per substance and functional unit for the two scenarios.

Potato is the crop that has the largest acidifying effect on the environment in this study (Figure 13). This can be explained by the high amount of field operations in potato cropping. It is also a consequence of the high amount of required phosphorus fertilisers, which in the production phase emits SO_2.

Again, the cultivation of oats shows the largest diversion between the chemical and mechanical scenario. This is related to the weed control.

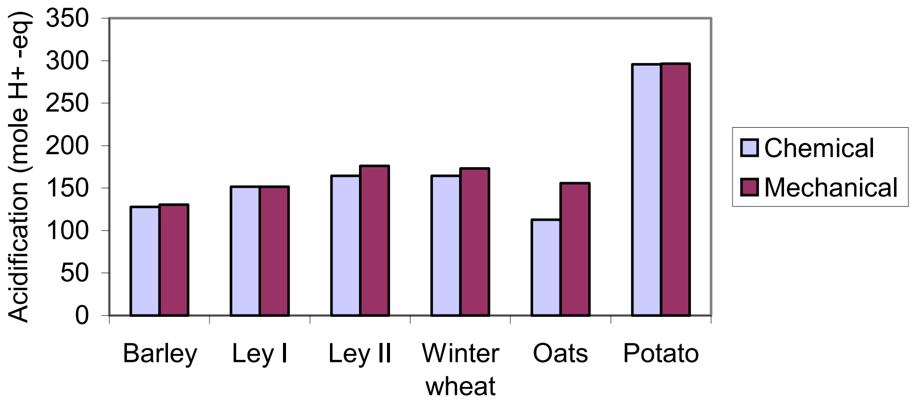

Figure 13. Contribution to acidification for the different crops in the two scenarios.

6.5 Photo-oxidant formation

As Figure 14 shows, the mechanical scenario has a slightly larger impact on photo-oxidant formation than the chemical scenario. HC gives the greatest contribution to photo-oxidant formation. Emissions of HC mainly occur in field operations. Emission of CO originates from field operations and production of mineral fertilisers.

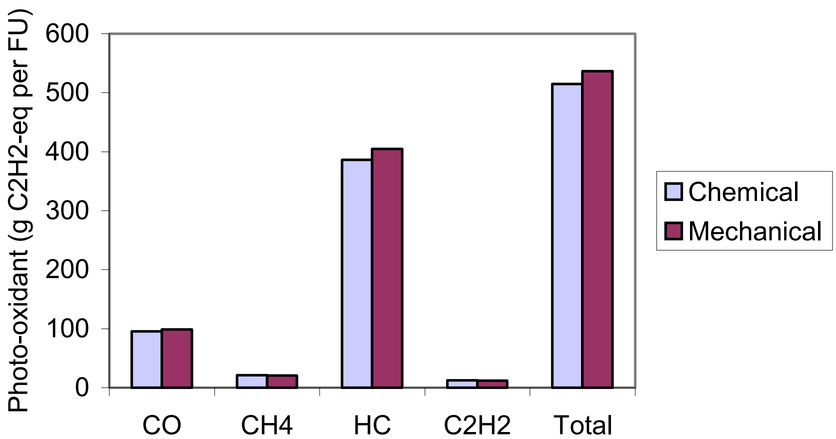

Figure 14. The different substances contribution to photo-oxidant formation per functional unit.

Figure 15 indicates that oats again has the greatest difference between the chemical and the mechanical scenario. This can be explained by the higher emissions of HC and CO in the activity of stubble cultivation as the mechanical weed control.

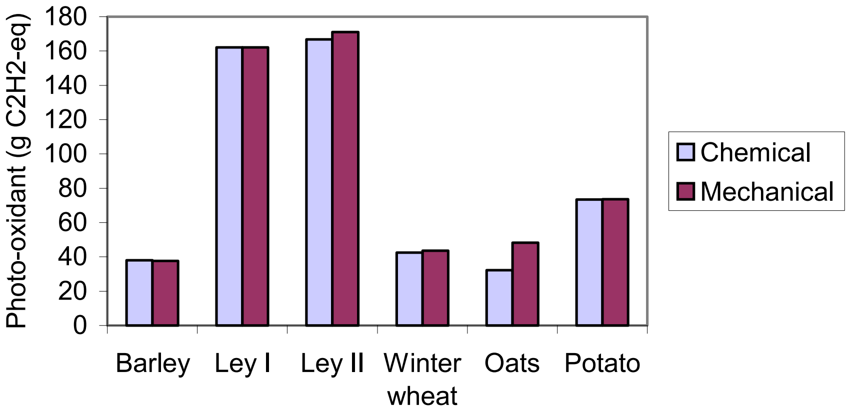

Figure 15. Contribution to photo-oxidant formation divided by crops in the two scenarios.

6.6 Pesticide use

In the chemical scenario 5.9 kg of active substance is in total used, compared with the mechanical scenario that uses 3.4 kg of active substance.

7 DISCUSSION

In the impact assessment it was indicated that the differences between the chemical and mechanical scenario in general were quite small. The weed control has little result on the environmental impact compared to the farming system in total. Other activities like mineral fertilisation showed to have a much larger impact on the environmental load of the system. So, in a well-planned crop sequence, a mechanical weed control do not necessarily cause much larger emissions than a chemical weed control system. It is also important to keep in mind that the difference not only lays in the studied impact categories, but also in the reduced amount of used chemicals.

The result also showed that the environmental burden between the different crops varied considerably. Potato cropping turned out to be the largest contributor to eutrophication, acidification, photo-oxidant formation and energy usage in both the chemical and mechanical scenario. The question is only; can the different crops be compared to each other? The answer is of course no. Ley for example serves as animal feed while winter wheat is grown for human consumption. Further, since the yield of potato is so much larger in mass, is it fair to say that potato has a high environmental load compared to the other crops? Nevertheless, it can be of interest to present the results per crop in order to facilitate the interpretation of the results.

If mechanical weed control does not increase the emission in any profound way and at the same time does not use potentially dangerous chemicals, what reasons are there to *not* use mechanical weed control? The economical issues are of course of importance. Herbicides are cheap and easy to use. But there are practical arguments as well. Mechanical weed control takes time. Also, since the result of weed harrowing often depends on the right timing, it is difficult to harrow all fields at the exact right time.

Another important question is the validity of this kind of study. LCA is only one of many environmental tools available. Since a farming system has a very complex pattern, a system analysis can be giving. But one must remember that an LCA of this kind is a very simplified version of real life. Several assumptions and limitations to other systems have been made which can effect the results in one way or the other. The data are gathered from many different sources and the quality of the data can sometimes be questioned. Some of these uncertainties are investigated in the sensitivity analysis, but far from all. As a conclusion it can be said that an LCA is a helpful tool that can point out in what direction we should move to keep the environmental impact as low as possible.

7.1 Sensitivity analysis

In a sensitivity analysis, changes in data are made in order to see what influence they have on the results.

7.1.1 Yields

An assumption that was made early in the study was the yields in the chemical and mechanical scenario. The yields in the mechanical scenario were considered to be lower. This effects the area of used land. What will happen with the results if the yield losses are higher?

Some new alternatives are tested, see Table 14. The new alternatives are based on the variations in the literature in chapter 4.3.2.

Table 14. Alternative yields in sensitivity analysis. Percent of chemical yield

	Chemical	Mechanical	Mechanical alt.2	Mechanical alt.3
Barley	100	90	88	85
Ley	100	100	100	100
Winter wheat	100	88	85	80
Oats	100	90	88	85
Potato	100	100	90	85

In Table 15 the effects of the alternative yields are shown. The use of energy and the impact on global warming is limited even in the third alternative where the yields are strongly reduced. The economical consequences of such reduced yields are on the other hand very large and this is not a sustainable way of cropping. The category eutrophication and acidification are more sensitive to variations in yields.

Table 15. Effects of alternative yields in percent compared to the chemical scenario

	Energy	GWP	Eutro	Acid
Chemical	0	0	0	0
Mechanical	+4	+2	+6	+7
Mechanical alt 2	+7	+4	+11	+11
Mechanical alt 3	+12	+8	+17	+16

7.1.2 Mechanical weed control

In this study, the weed pressure was not considered to be very high. If the cultivated land has a higher weed pressure, the mechanical weed control would have to be increased. How would that effect the results? Table 16 shows an alternative mechanical weed control that will be tested.

Table 16. Alternative increased mechanical weed control

Crop	Mechanical weed control
Barley	2 x weed harrowing
Ley I	-
Ley II	2 x stubble cultivation
Winter wheat	1 x weed harrowing
Oats	2 x weed harrowing
	2 x stubble cultivation
Potato	3 x weed harrowing and ridging

Table 17 shows the effect of an increased mechanical weed control compared to the basic mechanical scenario.

Table 17. Impact of increased mechanical weed control in percent of basic mechanical scenario

	Energy	GWP	Eutro	Acid
Increased mechanical control	+2.2	+1.0	+0.6	+2.6

7.2 Pesticides in the environment

In this study the environmental burden of a farming system with chemical weed control has been compared to one with mechanical weed control. In most aspects, the mechanical scenario proved to have a larger impact on the environment. But one important factor remains: the mechanical scenario uses fewer chemicals. This, of course is the true benefit of the mechanical scenario. The problem is only that this benefit is difficult to quantify. There are some models available for this type of quantification, ranging from ranking methods to mathematical models (Margini et. al, 2002). But most of these models are time consuming to perform and the accuracy of the results can be discussed.

7.3 Long term effects of weeds in a mechanical weed control system

A question that arose during this study is; what will happen in a longer time perspective with the weeds? Is there a chance that the seed bank eventually will increase if we stop using herbicides?

The amount of weeds has since the 1950s and the introduction of herbicides, been significantly reduced. Less weeds means less seeds and so a decrease in the seed bank has been obtained (Gummesson, 1988). During the 1950s the number of weeds in average was 500-600 per $m^{2.}$ today about 200 weeds are found per m^2. The comparance can of course be delicate; the situation today differs much regarding competitiveness of crops, weed composition, the reduced area of ley, tillage techniques, etc (Fogelfors, www).

In Denmark, some research has been done regarding seed bank and mechanical weed control. Tersbøl et al. (1998) states that some seeds can survive 15-20 years in the soil. In other words it can take some time before we see the effect of the weeds. It is therefore of great importance that the weeds are prevented from spreading their seeds.

Tersbøl et al. (1998) establish the fact that there are no trials done in Denmark that can indicate the connection between seed bank and mechanical weed control. Although, they make the qualified assumption that in a well-planned crop rotation, the mechanical weed control (direct and indirect) can be enough to reduce the number of weeds so much that the seed bank does not increase.

In Kristianstad, Sweden, a field trial has been conducted during 12 years comparing conventional and organic farming. Five different farming systems were included in the experiment: conventional without animals, conventional with animals, biodynamical with animals, organically without animals and organically with animals (Ivarsson, 2003). In this trial, the number of weed has been counted continuously in the different farming systems, for example see Table 18. The crop rotation is well balanced with ley (in animal farming system), spring and winter crops, potato and beets.

Table 18. Results from inventory of seed-propagated weed in spring cereals after 12 years of trials. Average from three experimental fields

Farming system	Plants per m^2	Number of species
Conv. without animals	311	12
Conv. with animals	250	12
Biodynamical with animals	221	17
Organically with animals	221	16
Organically without animals	582	17

It can be noticed that in the organical farming systems with animals, the amount of weeds per area is less than in corresponding conventional system. This implies that the weeds are kept under satisfactory control even without herbicides. The number of species on the other hand increased which indicates that the organical system holds a higher biodiversity. Further, in organical farming systems no mineral fertilisers are used which often leads to lower yields. In a thin crop the competitiveness of weeds increase, but even so the weed pressure was kept under control in this trail.

During 1974-1989 field trials were conducted by the Swedish University of Agricultural Science, that compared chemical and mechanical weed control (Gummesson, 1990). The crop rotation consisted of cereals only, mostly spring sown. The results showed that annual weeds increased, although the increase was moderate. The weed harrowing gave moderate results on the weeds, especially during the later part of the trials. It was noticed that some of the weeds that were more resistant to harrowing were favoured.

The Royal Swedish Academy of Agriculture and Forestry published a report in 1989. in which the consequences of reduced doses of herbicides were investigated. They confirm the fact that there are very few trials that study long-term effects of different farming systems. In order to make a reasonable guess of the long-term effects in the seed bank, a theoretical model was developed. In the differential equation on which the model is built upon consideration is taken regarding the amount of seeds being destroyed and the amount of seeds that is brought on to the field for example by wind drift. The model was applied to several different farming systems. The results strongly depended on if ley was included in the crop sequence and if the preceding spring was dry. In the worst scenario when no herbicides were used, the number of seeds was four times larger than the initial amount within 3 years. In the best scenario without herbicides, the seed bank had only slightly increased after 10 years.

Many trials have been conducted investigating the connection between dose of herbicides and the development of weeds. This can perhaps be applied to mechanical weed control evaluation. Gummesson et al. (1988) points out that the recommended dose of herbicide gives 80-90% efficacy on weeds. This can be justified on fields with very high weed pressure. But in normal situations a weed efficacy of 70-80% is enough. The question is hence; can we reach a 70-80% reduction of weeds in a mechanical weed control system? Mattsson & Sandström (1994) investigated the effect on weeds in cereals and oil plants. They reached the conclusion that the reduction of weeds depends on a number of factors, for example soil characteristics. The efficacy can according to Mattsson & Sandström vary between 30-85%. It must be remembered that these are only the effects of *direct* weed control. What influence the indirect weed control has is probably more difficult to put in figures.

7.3 Humus content

The humus content is a measure of how much organic matter there is in the soil. In a farming system with intensive tillage the biological turnover is stimulated. The question is hence, will the humus content decrease in the mechanical scenario? A decrease in the humus content could lead to a number of negative effects in the soil: reduced ability to hold water and nutrients, structure change and a larger risk surface run-off and erosion (Fogelfors, 2001).

The humus content strongly depends on the how much organic matter the soil is applied through manure and crop residues. The crop sequence is also of importance. Ley builds up the humus content while crops like potato lowers it. As mentioned earlier the amount of tillage can effect the humus content as well (Fogelfors, 2001).

In this study all straw is reincorporated to the soil, ley is grown in both scenarios and the differences in tillage between the scenarios are quite small. Considering this, it can be reasonable to say that the decrease in the humus content for the mechanical scenario compared to the chemical is negligible.

7.4 Machinery

In many LCAs, the production of capital goods such as machinery and buildings are left out since the effect on the results is considered to be small. In this study however, it might be interesting to investigate the difference between the scenarios since the mechanical scenario uses a weed harrow. Data for energy use for producing, manufacturing and for spare parts are taken from Bernesson (2003). In Table 19 data is presented for one occasion of harrowing. In the mechanical scenario weed harrowing takes place at a total of five times during the studied period.

Table 19. Energy use for one occasion of harrowing on one hectare (Bernesson, 2003)

Use	Weight	Durability	Input	Tied-up energy for: (MJ/kg machine)				Energy
(h/ha)	(kg)	(h)	(kg/ha)	Raw material	Manu-facture	Spare parts	Total	(MJ/ha)
0.27	1 700	1 000	0.46	21.6	5.40	12.56	39.56	18.2

As the cultivated land in the mechanical scenario is 6.36 ha the energy added for the extra harrow is 18.2 x 5 x 6.36 = 579 MJ. Considering that the total energy use in the mechanical scenario was 61 080 MJ, the effect of extra machinery is marginal.

8 REFERENCES

8.1 Literature

Arnäs, P.O., Blinge, M., Bäckström, S., Furnander, Å. & Hovelius K. 1997. *Livscykelanalys av drivmedel – en studie med utgångspunkt från svenska förhållanden och bästa tillgängliga teknik.* Chalmers University of Technology. Transportation and logistics. Gothenburg. Sweden.

Andersson, C. 2001. *Växtodlarens när vad hur*. Odal. Lidköping. Sweden.

Bernes, C. 2001. *Läker tiden alla sår? Om spåren efter människans miljöpåverkan*. Monitor 17. Naturvårdsverkets förlag. Sweden.

Bernesson, S. 2003. *Life cycle assessment of rapeseed oil, rape methyl ester and ethanol as fuel – a comparison between small- and largescale production*. Unpublished report. Department of Agricultural Engineering. Swedish University of Agricultural Science. Uppsala. Sweden.

Bodström, U. 1999. Type and time of autumn tillage with and without herbicides at reduced rates in southern Sweden. Yields and weed quality. *Soil and Tillage Research.* Issue 50 (1999). Department of Crop Production Science. Swedish University of agricultural science. Sweden.

Cederberg, C.1998. *Life Cycle Assessment of Milk Production. A comparison of Conventional and Organic Farming*. SIK-Report no 643. The Swedish Institute for Food and Biotechnology. Gothenburg. Sweden.

Cowell, S.& Clift, R. 1995. *Life Cycle Assessment for Food Production Systems.* The Fertiliser Society. Peterborough. England.

Dalemo, M. Jonsson, B. Oostra, H. & Sundberg, M. 1997. *Hanteringssystem för råvara och rötrest vid storskalig rötning av växtmaterial*. JTI rapport. Kretslopp & avfall No 9. Uppsala. Sweden.

Davis, J. & Haglund, C. 1999. *Life Cycle Inventory (LCI) of Fertiliser Production. Fertiliser Products Used in Sweden and Western Europe*. SIK-Report no 654. The Swedish Institute for Food and Biotechnology. Gothenburg. Sweden.

Emmerman, A., Franzén, M., Sundgren, A. & Bergkvist, P. 2002. *Förslag till handlingsprogram för användningen av bekämpningsmedel i jordbruket och trädgårdsnäringen till år 2006*. Rapport 2002:7. Jordbruksverket. Jönköping. Sweden.

Fischer, A & Hallgren E. 1991. *Ogräsbekämpning i olika växtodlingssystem; en jämförelse*. Svenska växtskyddskonferensen. Institutionen för växtodlingslära. The Swedish University of Agricultural Science. Uppsala. Sweden.

Fogelfors, H (editor). 1995. *Ogräsnyckeln*. Speciella skrifter 59. The Swedish University of Agricultural Science. Uppsala. Sweden.

Fogelfors, H. (editor). 2001. *Växtproduktion i jordbruket*. Natur och kultur/LTs förlag. Borås. Sweden.

Gummesson, G., Olofsson, B., Hallqvist, H., Bengtsson, A. & Fogelfors H. 1988. *Kan kemisk bekämpning minskas?* Aktuellt från lantbruksuniversitetet 370. The Swedish University of Agricultural Science. Uppsala. Sweden.

Gummesson, G. 1990. *Resultat från en långliggande försöksserie med kemisk och icke kemisk ogräsbekämpning*. 31: a svenska växtskyddskonferansen. Ogräs och ogräsbekämpning. Rapporter. The Swedish University of Agricultural Science. Uppsala. Sweden.

Gummesson, G. 1992. *Ogräsbekämpning i olika odlingssystem*. Aktuellt från lantbruksuniversitetet 404. The Swedish University of Agricultural Science. Uppsala. Sweden.

Hammar, O. (editor). 1990. *Växtodling 2. Växterna*. LTs förlag. Borås. Sweden.

Hansson, P-A., Mattsson, B. 1999. Influence of Derived Operation-Specific Tractor Emission Data on Results from an LCI on Wheat Production. *International Journal of Life Cycle Assessment*. Landsberg. Germany.

IPPC. 1997. *Greenhouse Gas Inventory Reference Manual*. Volume no 3. Revised 1996 IPPC Guidelines for National Greenhouse Gas Inventories.

Ivarsson, J. 2003. *Jämförelse mellan konventionella och ekologiska odlingssystem – resultat från tolv års försök 1987-1998*. Utgåva 1 2003. Hushållningssällskapet Kristianstad. Klippan. Sweden.

ISO 14041. 1998. *Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis*. European Committee for Standardization.

Jordbruksverket. 2002. *Jordbruksstatisktisk årsbok*. (Yearly statistics from the Swedish board of agriculture). Rapport 2002:11. Sweden.

Kaltschmitt, M. & Reinhardt, G.A., 1997. *Nachwachsende Energieträger - Grundlagen, Verfahren, ökologische Bilanzierung.* Vieweg & Sohn Verlagsgesellschaft mbH. Braunschweig/Wiesbaden. Germany.

Kreuger, J. 1999. *Pesticides in the Environment – Atmospheric Deposition and Transport to Surface Waters*. Doctoral Thesis. Agraria 162. The Swedish University of Agricultural Science. Uppsala. Sweden.

Lindahl, M., Rydh, C.J. & Tingström, J. 2001. *En liten lärobok om livscykelanalys*. Institutionen för teknik. Högskolan i Kalmar. Kalmar. Sweden.

Lindfors, L-G., Christiansen, K., Hoffman, L., Virtanen, Y., Juntilla, V., Hansen, O-J., Rønning, A. Ekvall, T. & Finnveden, G. 1995. *Nordic Guidelines on Life-Cycle Assessment*. Nordic Council of Ministers. Nord 1995:20.

Lindgren, M., Pettersson, O., Hansson, P-A., Norén, O. 2002. *Jordbruks- och anläggningsmaskiners motorbelastning och avgasemissioner – samt metoder att minska bränsleförbrukning och avgasemissioner*. Swedish Institute for Agricultural and Environmental Engineering (JTI). Sweden.

Lundkvist, A. & Fogelfors, H. 1999. *Ogräsreglering på åkermark*. Rapport 1. Institutionen för växtproduktionslära. The Swedish University of Agricultural Science. Uppsala. Sweden.

Margini, M., Rossier, D., Crettaz, P. & Jolliet, O. 2002. Life cycle impact of pesticides on human health and ecosystems. *Agriculture, Ecosystems and Environment*. 93 (2002) 379-392. Elsevier.

Mattsson, B. & Sandström, M. 1994. *Icke-kemisk bekämpning i stråsäd och oljeväxter*. Aktuellt från lantbruksuniversitetet 423. The Swedish University of Agricultural Science. Uppsala. Sweden.

Mattsson, B. 1999. *Environmental Life Cycle Assessment (LCA) of Agricultural Food Production*. Doctoral Thesis. Agraria 187. The Swedish University of Agricultural Science. Alnarp. Sweden.

Mattsson, B., Wallén, E., Blom, A. & Stadig, M. 2002. *Livscykelanalys av ekologisk matpotatis.* The Swedish Institute for Food and Biotechnology, SIK. Gothenburg. Sweden.

Nilsson, L.G. 1992. *Inverkan av odlingssystem, växtnäringsnivå och jordart på ogräsens utveckling*. Ogräs och ogräsbekämpning. Svenska växtskyddskonferensen. Institutionen för växtodlingslära. The Swedish University of Agricultural Science. Sweden.

The Royal Swedish Academy of Agriculture and Forestry. Kungliga skogs- och lantbruksakademin. 1989. *Minskad bekämpning i jordbruket. Möjligheter och konsekvenser.* Report no 36. Stockholm. Sweden.

STANK. *Teknisk beskrivning av utlakningsberäkningen i kalkylprogrammet STANK 4.11*. Jordbruksverket.

Tersbøl, M., Mikkelsen, G., Rasmussen, I. & Christensen, S. 1998. *Forebyggelse af ukrudtsproblemer, samt mekanisk bekæmpelse af ukrudt og effekter på frøpuljen*. Bistand til utvalgsarbejdet til vurdering af de samlade konsekvenser af en afvikling af pesticidanvendelsen. Denmark.

Tidåker, P. 2003. *Life Cycle Assessment of Grain Production Using Source-Separated Human Urin and Mineral Fertiliser*. Doctoral Thesis. Report 251. Department of Agricultural Engineering. Swedish University of Agricultural Science. Uppsala. Sweden.

Tillman, A-M. Buamann, H. Eriksson, E. & Rydberg, T. 1991. *Livscykelanalyser för förpackningsmaterial. Beräkning av miljöbelastning*. Statens offentliga utredningar. Stockholm. Sweden.

Ulén, B. 1997. *Förluster av fosfor från jordbruksmark*. Naturvårdsverket. Report no 4731. Sweden.

Uppenberg, S., Almemark, M., Brandel, M., Lindfors, L-G., Marcus, H-O., Stripple, H., Wachtmeister, A. & Zetterberg, L. 2001. *Miljöfaktabok för bränsle. Del 1. huvudrapport. Del 2. bakgrundsinformation och teknisk bilaga.* IVL Svenska Miljöinstitutet AB. Report B 1334 A-2 respektive B 1334B-2. Stockholm. Sweden.

Välimaa, C & Stadig, M. 1998. *Växtnäring i livscykelanalys*. SIK-Report no 637. The Swedish Institute for Food and Biotechnology. Gothenburg. Sweden.

8.2 Personal communication

Lindgren, M. Doctoral student, Department of Agricultural Engineering, Swedish University of Agricultural Science. 018-671239. 2003-08-18.

Wivstad, M. Researcher. Centre for Sustainable Agriculture. Swedish University of Agricultural Science. 018-67 14 09. 2003-06-11.

8.3 Internet

Agriwise. *Databok 2003*. http://www.agriwise.org 2003-08-11

Bichel-udvalget. 1999. *Rapport fra underudvalget om jordbrugsdyrkning*. Udvalget til vurdering af de samlade konsekvenser af en hel eller delvis afvikling af pesticidanvendelsen. Denmark. http://www.mst.dk 2003-06-03

Bovin, H. 1999. *Reglering av rotogräs i ekologiskt lantbruk.* http://www.vaxteko.nu. 2003-10-29

Fogelfors, H. 1992. *Hur påverkar omställningen ogrässituationen på våra åkrar*? http://www.vaxteko.nu. 2003-09-18

IPCC. 2001. *Climate Change 2001. The scientific basis. Contribution of Working group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* http://www.grida.no/climate/ipcc_tar/wg1/index.htm 2003-08-20

Livsmedelsverket. National Food Administration. *Mat och Hälsa, riskbedömning.* http://www.slv.se/templatesSLV/SLV_Page__3459.asp. 2003-09-29

Miljömålsportalen. *Våra 15 miljömål*. http://www.miljomal.nu. 2003-10-16

NTM. *The Network for Transport and the Environment*. http://www.ntm.a.se. 2003-09-02

APPENDIX 1. CHARACTERISATION FACTORS

Table 1. Characterisation factors used in this study

	Global warming[1] (g CO_2-eq/g)	Adicification[2] (mole H+ eq/g)	Eutrophication[3] (g O_2-eq/g)	Photo-oxidant formation[4] (g C_2H_2-eq/g)
CO_2	1			
CH_4	23			0.007
N_2O	296			
CO				0.032
C_2H_2				1
HC				0.416
SO_2		0.031		
NO_x		0.022	6	
NH_3		0.059	16	
COD			1	
N to water			20	
P to water			140	
NO_3^-			4.4	

1. Source: IPCC (www) 100-year perspective.
2. Source: Lindfors et al.. (1995) maximum scenario
3. Source: Lindfors et al.. (1995) maximum scenario
4. Source: Lindahl et al. (2001)

APPENDIX 2. EXHAUST EMISSIONS FROM FIELD OPERATIONS.

Table 1. Emissions from Valtra 6600 for different field operations(Lindgren et al., 2002.

Operation	Fuel kg/ha	CO_2 g/ha	CO g/ha	HC g/ha	NO_x g/ha
Harrowing autumn 70 tines	2.8	9 100	6.7	2.6	93
Harrowing spring 70 tines	2.8	9 100	6.7	2.6	94
Stretch film coater	4.7	15 500	21.2	5.6	225
Ploughing 4 furrow reversible	14.4	46 700	32.8	11.0	530
Mower conditioner	5.1	16 600	10.2	3.7	202
Stubble cultivation	12.7	41 200	24.0	8.6	450
Sowing	4.2	13 700	12.8	4.7	138
Spreading of artificial fertiliser	0.4	1 300	2.9	0.7	17

Table 2. Emissions from thresher Massey Ferguson (Lindgren et al., 2002)

Operation	Fuel kg/ha	CO_2 g/ha	CO g/ha	HC g/ha	NO_x g/ha
Wheat	13.4	43 600	163	7.1	505
Barley	14.5	47 200	134	8.0	469
Oats	11.8	38 400	104	6.6	368

Table 3. Emissions from different operations in potato cropping (Lindgren et al., 2002; Mattsson et al., 2002.

Operation	Fuel kg/ha	CO_2 g/ha	CO g/ha	HC g/ha	NO_x g/ha
Planting	8.2	26 600	15.5	5.5	291
Ridging	5.7	18 500	13.6	5.4	191
Lifting	41.0	133 200	73.0	25.1	1463

APPENDIX 3. PRODUCTION OF DIESEL AND ELECTRICITY

Table 1. Environmental impact of production and distribution of diesel (Mk1) per MJ diesel (Uppenberg et al., 2001)

Per MJ of diesel	
Energy usage, MJ	0.06
Emissions to air, mg	
NO_x	31
SO_x	19
CO	2.0
NMVOC	33
CO_2	3 500
CH_4	2.0
Particles	1.0
Emissions to water, mg	
Oil	5.0
N	0.07
P	0.01

Table 2. Emissions from electricity production (Uppenberg et al., 2001)

Total environmental impact per MJ produced electricity	
Energy usage, MJ	0.032
Emission to air, mg	
NO_x	15
SO_x	13
CO	18
NMVOC	2.9
CO_2	7842
N_2O	0.71
CH_4	49
Particles	2.5
NH_3	0.22

APPENDIX 4. PRODUCTION OF PESTICIDES

Table 1. Energy use and emissions from production of pesticides (Kaltschmitt & Reinhardt, 1997)

Environmental impact per kg active substance	
Energy (MJ)	
Total	198.1
Diesel	58.1
Heating oil	32.5
Natural gas	71.4
Electricity	36.1
Emissions (g)	
CO_2	4921
CH_4	0.18
N_2O	1.51
SO_2	17.4
CO	2.66
NO_x	6.92
HCl	0.21
NH_3	0.16

APPENDIX 5. PRODUCTION AND TRANSPORT OF MINERAL FERTILISER

Table 1. Inventory matrix of emissions from production of 1 kg of N, P and K respectively. From Davis & Haglund (1999)

	N	P	K
Energy (MJ)			
Diesel	1.16	10.2	
Electricity	0.743	8.41	
Hard coal	3.95		
Heavy fuel oil	4.34	12	
Natural gas	316		6.02
Heat production	-0.906		
Unspecified fuel	1.15E-06	4.54E-06	
Emissions (g)			
CH_4	3.04	5.67	0.0247
CO	1.49	4.24	0.0864
CO_2	2950	3080	375
Ethene	0.0118		
N_2O	14.6	0.287	8.84E-04
NH_3	0.212	1.46E-03	
NO_x	5.72	18.3	0.373
SO_2	4.84	38.3	4.45E-03
COD	4.42E-03	0.035	
Tot-N	0.487	0.096	
Tot-P	6.79E-06	3.30	

Table 2. Emissions from transports with heavy truck Euro 3 and with diesel Mk1 (g/ton and kilometre). From NTM (www)

Emission	g/tkm
CO_2	46
NO_x	0.28
HC	0.023
CO	0.040
PM	0.796
SO_2	5.7E-05
Energy fossil [kW]	0.17

APPENDIX 6. PRODUCTION OF STRETCH FILM

Table 1. Environmental impact per kilo of LDPE. Production and waste handling (landfill). From Tillman et al. (1991)

Energy (MJ/kg)	
Electricity	11.529
Thermal energy	60.398
Diesel for fuel	0.476
Fuel boat	0.0248
Emissions (g/kg)	
SO_2	0.959
NO_x	1.988
HC	11.22
CO_2	1023

APPENDIX 7. BARLEY CHEMICAL SCENARIO

	Energy (MJ)			Emissions to air (g/ha)								Emissions to water (g/ha)				
Yield (kg/ha) 4436																
Area (ha) 1																
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1 x ploughing	619		619	46700	33		11.0			530	58					
3 x harrowing	361		361	27300	20		7.8			282	34					
2 x sowing	361		361	27400	26		9.4			276	34					
1 x fertilising	17		17	1300	3		0.7			17	2					
2 x spraying (herbicides)	96		96	5800	5		2.0			60	9					
0.6 x spraying (pesticides)	29		29	1740	2		0.6			18	3					
1 x harvest	624		624	47200	134		8.0			469	58					
Sum	**2107**		**2107**	**157440**	**222**		**39.5**			**1652**	**197**					
Inputs																
Fertiliser production	224	168	3881	288840	177	315		1157	16.8	705	880	1.5	0.8	39.7	42.9	
Transport of fertiliser	14		14	1079	1		0.5			7	0					
Pesticide production	8	5	28	684	0.4	0.03		0.2	0.0	1	2					
Herbicide production	22	14	75	1875	1.0	0.07	0	0.6	0.1	3	7					
Seed production	115	8	123	21198	19	15	1.9	108	21.9	116	52	0.07	0.04	1.78	11.7	469
Electricity production			205	1530	3.5	10		0.1	0.0	3	3					
Diesel production			149	8718	5	5				77	48			0.18	0.0	
Other emissions																
N from soil								1255	474							10500
P from soil															220	
Transports to/from field	211		211	15744	22		4.0			165	20					
Sum total	**2702**	**195**	**6794**	**497104**	**451**	**344**	**46**	**2521**	**513**	**2729**	**1208**	**1.6**	**0.8**	**42**	**275**	**10969**

APPENDIX 8. BARLEY MECHANICAL SCENARIO

		Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
Yield (kg/ha)	3992																
Area (ha)	1.11122																
		Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																	
1 x ploughing		688		688	51894	36		12			589	64					
3 x harrowing		401		401	30336	22		9			313	38					
1 x sowing		201		201	15224	14		5			153	19					
1 x fertilising		19		19	1445	3		1			19	2					
1 x weed harrowing + sowing of ley		143		143	10112	7		3			104	13					
0.6 x spraying (pesticides)		32		32	1934	2		1			20	3					
1 x harvest		693		693	52450	149		9			521	65					
Sum		**2178**		**2178**	**163394**	**234**		**39**			**1720**	**204**					
Inputs																	
Fertiliser production		226	170	3856	287507	176	313		1140	17	706	877	1.5	1	35	40	
Transport of fertiliser		14		14	1079	1	0	1			7	0					
Pesticide production		9	6	31	760						1	3					
Seed production		145	10	155	26354	24	18	2	133	27	148	64	0.08	0.04	2	16	643
Electricity production				194	1452	3	9		0	0	3	2					
Diesel production				154	9002	5	5				80	49			0.2	0.03	
Other emissions																	
N from soil									1269	467							11668
P from soil																244	
Transports to/from field		218		218	16339	23		4			172	20					
Sum total		**2790**	**185**	**6800**	**505587**	**468**	**345**	**46**	**2541**	**510**	**2836**	**1230**	**1.5**	**0.86**	**42**	**304**	**12311**

APPENDIX 9. LEY I CHEMICAL AND MECHANICAL SCENARIO

		Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
Yield (kg/ha)	6586																
Area (hectar)	1																
		Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																	
2 x fertilising		34		34	2600	6		1			34	3					
2 x mowing		439		439	33200	20		7			404	41					
2 x plastic coating		404		404	31000	42		11			450	38					
Sum		**877**		**877**	**66800**	**69**		**20**			**888**	**82**					
Inputs																	
Fertiliser production		342	251	7009	514985	296	539		2122	31	1175	1353	2.73	1.24	72	56	
Transport of fertiliser		27		27	2053	2	0	1			12						
Seed production		69		251	15575	8	13		47	1	33	38		0.03	2	2	647
Electricity production				606	4526	10	28				9	8					
Diesel production				82	4604	3	3				41	25			0.1	0.01	
Stretch film		13	326	2051	28971			318			56	27					
Other emissions																	
N from soil									2040	870							8750
P from soil																220	
Transports to/from field		88		88	6680	7		2			89	8					
Sum total		**1417**	**577**	**10988**	**644194**	**395**	**584**	**341**	**4210**	**902**	**2303**	**1541**	**2.73**	**1.3**	**74**	**278**	**9397**

APPENDIX 10. LEY II CHEMICAL SCENARIO

	Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
Yield (kg/ha) 6586																
Area (hectar) 1																
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1x fertilising	17		17	1300	3		1			17	2					
2x mowing	439		439	33200	20		7			404	41					
2x plastic coating	361		361	31000	42		11			450	38					
1x spraying Roundup	48		48	1300	3		1			17	2					
1x stubble cultivation	546		546	41200	24		9			450	51					
Sum	**1411**		**1411**	**108000**	**93**		**29**			**1338**	**133**					
Inputs																
Fertiliser production	342	251	7310	533735	300	541		2122	31	1194	1354	2.73	1.24	72	56	
Transport of fertiliser	33		33	2455	2		1			15						
Herbicide production	73	45.5	250	6200	3	0.2		2	0.2	9	22					
Electricity production			654	4883	11	31		0.4	0.1	9	8					
Diesel production			112	6505	4	4				58	35			0.13	0.02	
Stretch film	13	326	2051	28971			318			56	27					
Other emissions																
N from soil								2477	870							26250
P from soil															220	
Transports to/from field	141		141	10800	9		3			134	13					
Sum total	**2013**	**622.7**	**11961**	**701550**	**423**	**575**	**350**	**4602**	**901**	**2813**	**1592**	**2.7**	**1.2**	**72**	**276**	**26250**

APPENDIX 11. LEY II MECHANICAL SCENARIO

	Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
Yield (kg/ha) 6586																
Area (hectar) 1																
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1x fertilising	17		17	1300	3		1			17	2					
2x mowing	439		439	33200	20		7			404	41					
2x plastic coating	361		361	31000	42		11			450	38					
2x stubble cultivation	1092		1092	82400	48		17			900	102					
Sum	**1909**		**1909**	**147900**	**114**		**37**			**1771**	**183**					
Inputs																
Fertiliser production	342	251	7310	533735	300	541		2122	31	1194	1354	2.73	1.24	72	56	
Transport of fertiliser	27		27	2053	2		1			12						
Electricity production			606	4526	10	28		0.4	0.1	9	8					
Diesel production			137	7973	5	5				71	43			0.2	0.0	
Stretch film	13	326	2051	28971			318			56	27					
Other emissions																
N from soil								2477	870							26250
P from soil															220	
Transports to/from field	191		191	14790	11		4			177	18					
Sum total	**2483**	**577**	**12231**	**739949**	**442**	**574**	**359**	**4600**	**901**	**3290**	**1632**	**2.7**	**1.2**	**72**	**276**	**26250**

APPENDIX 12. WINTER WHEAT CHEMICAL SCENARIO

	Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
Yield (kg/ha) 5657																
Area (hectar) 1																
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1x ploughing	619		619	46700	33		11			530	58					
3x harrowing	361		361	27300	20		8			282	34					
1x sowing	181		181	13700	13		5			138	17					
2x fertilising	34		34	2600	6		1			34	3					
2x spraying (herbicides)	96		96	5800	5		2			60	9					
1.3x spraying (pesticides)	63		63	3770	4		1			39	6					
1x harvest	576		576	43600	163		7			505	54					
Sum	**1930**		**1930**	**143470**	**243**		**35**			**1588**	**180**					
Inputs																
Fertiliser production	322	238	6043	447960	267	487		1874	27	1061	1271	2.41	1.16	64	56	
Transport of fertiliser	21		21	1554	1		1			9	0					
Pesticide production	26	16	88	2190	1	0.08		1	0.07	3	8					
Herbicide production	7	4	24	586	0.3	0.02		0.2	0.02	1	2					
Seed production	101	11	112	25280	22	21	2	160	32	118	62	0.10	0.05	3	11	715
Electricity production			282	2109	5	13		0.2	0.06	4	3					
Diesel production			144	8424	5	5				75	46			0	0	
Other emissions																
N from soil								2045	768							17500
P from soil															220	
Transports to/from field	193		193	14347	24		4			159	18					
Sum total	**2600**	**269**	**8837**	**645919**	**569**	**525**	**41**	**4080**	**828**	**3018**	**1591**	**2.5**	**1.2**	**67**	**287**	**18215**

APPENDIX 13. WINTER WHEAT MECHANICAL SCENARIO

		Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
Yield (kg/ha)	4978																
Area (hectar)	1.13640																
		Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																	
1x ploughing		704		704	53070	37		13			602	66					
3x harrowing		410		410	31024	23		9			320	38					
1x sowing		205		205	15569	15		5			157	19					
2x fertilising		39		39	2955	7		2			39	4					
1.3x spraying (pesticides)		71		71	4284	4		1			44	7					
1x harvest		709		709	49547	185		8			574	61					
Sum		**2138**		**2138**	**156448**	**270**		**38**			**1736**	**195**					
Inputs																	
Fertiliser production		325	240	6173	457202	271	495		1913	28	1079	1286	2	1	65	56	
Transport of fertiliser		21		21	2455	2.1		1.2			15						
Pesticide production		29	18	100	2489	1.4	0.1		0.8	0.08	3.5	8.8					
Seed production		143	14	156	33919	31	27	2	200	43	162	82	0.13	0.06	3	16	1049
Electricity production				286	2136	5	13		0.2	0.06	4	4					
Diesel production				159	9297	5	5				82	50			0.19	0.03	
Other emissions																	
N from soil									1882	784							19887
P from soil																250	
Transports to/from field		214		214	15645	27		4			174	19					
Sum total		**2870**	**272**	**9247**	**679591**	**613**	**541**	**45**	**3996**	**855**	**3256**	**1645**	**2.6**	**1.2**	**69**	**322**	**20936**

APPENDIX 14. OATS CHEMICAL SCENARIO

Yield (kg/ha) 4021 Area (hectar) 1	Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1x ploughing	619		619	46700	33		11			530	58					
3x harrowing	361		361	27300	20		8			282	34					
1x sowing	181		181	13700	13		5			138	17					
1x fertilising	17		17	1300	3		1			17	2					
1x spraying (herbicides)	48		48	2900	3		1			30	4					
0.5x spraying (pesticides)	24		24	1450	1		1			15	2					
1x harvest	507		507	38400	104		7			368	47					
Sum	**1758**		**1758**	**131750**	**177**		**32**			**1380**	**164**					
Inputs																
Fertiliser production	204	153	3470	258460	159	282		1025	15	635	799	1.32	0.73	35	40	
Transport of fertiliser	13		13	982	0.9		0.5			6	0.001					
Pesticide production	7	5	25	615	0.3	0.0		0.2	0.0	1	2					
Herbicide production	30	19	103	2559	1.4	0.1		0.8	0.1	4	9					
Seed production	122	10	328	23301	20	17	2	131	24	125	58	0.07	0.04	2	15	981
Electricity production			195	1459	3	9		0	0	3	2					
Diesel production			128	7468	4	4				66	41			0.15	0.02	
Other emissions																
N from soil								1317	420							17500
P from soil															220	
Transports to/from field	176		176	13175	18		3			138	16					
Sum total	**2310**	**186**	**6196**	**439770**	**383**	**312**	**38**	**2475**	**459**	**2357**	**1092**	**1.4**	**0.8**	**37**	**274**	**18481**

APPENDIX 15. OATS MECHANICAL SCENARIO

	Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
Yield (kg/ha) 3619																
Area (hectar) 1.11108																
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1x ploughing	688		688	51887	36		12			589	64					
3x harrowing	401		401	30332	22		9			313	38					
1x sowing	201		201	15222	14		5			153	19					
1x fertilising	19		19	1444	3		1			19	2					
2x weed harrowing	268		268	20222	15		6			209	25					
2x stubble cultivation	1214		1214	91553	53		19			1000	113					
0.5x spraying (pesticides)	27		27	1611	1		1			17	2					
1x harvest	564		564	42665	116		7			409	53					
Sum	**3381**		**3381**	**254937**	**261**		**60**			**2709**	**316**					
Inputs																
Fertiliser production	205	154	3445	256693	158	280		1009	15	633	802	1	1	35	40	
Transport of fertiliser	13		13	982	0.9		0.5			6.0	0.0					
Pesticide production	7	5	25	615	0.3	0.02		0.19	0.02	0.9	2.2					
Seed production	273	11	284	38260	32	20	5	154	30	259	85	0.09	0.05	2	20	1346
Electricity production			178	1329	3	8		0	0	3	2					
Diesel production			233	13575	8	8				120	74			0.27	0.04	
Other emissions																
N from soil								1216	413							19444
P from soil															244	
Transports to/from field	338		338	25494	26		6			271	32					
Sum total	**4217**	**169**	**7896**	**591885**	**489**	**316**	**71**	**2380**	**458**	**4001**	**1312**	**1.4**	**0.8**	**37**	**305**	**20790**

APPENDIX 16. POTATO CHEMICAL SCENARIO

Yield (kg/ha) 22212																
Area (ha) 1																
	Energy (MJ)			**Emissions to air (g/ha)**									**Emissions to water (g/ha)**			
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1x ploughing	619		619	46700	33		11			530	58					
2x deep cultivation	1092		1092	82400	48		17			900	102					
1x fertilising	17		17	1300	3		1			17	2					
1x planting	353		353	26600	16		6			291	33					
2x ridging	490		490	37000	27		11			382	46					
2x spraying (herbicides)	96		96	5800	5		2			60	9					
9.3x spraying (pesticides)	447		447	26970	25		9			279	42					
1x harvest	1763		1763	133200	73		25			1463	165					
Sum	**4878**		**4878**	**359970**	**230**		**82**			**3922**	**456**					
Inputs																
Fertiliser production	664	530	5768	457230	368	564		1184	17	1531	2533	1.50	2.31	44	185	
Transport of fertiliser	28		28	2141	2		1			13	0					
Pesticide production	155	96	527	13090	7	0.5		4	0.4	18	46					
Herbicide production	17	11	58	1437	0.8	0.05		0.4	0.05	2	5					
Seed production	768	79	1592	110946	81	76	11	364	62	753	398	0.19	0.29	6	50	3683
Electricity production			752	5613	13	35		1	0	11	9					
Diesel production			391	22784	13	13				202	124			0.5	0.07	
Other emissions																
N from soil								1749	480							29750
P from soil															220	
Transports to/from field	488		488	35997	23		8			392	46					
Sum total	**6997**	**716**	**14481**	**1009208**	**737**	**688**	**102**	**3301**	**559**	**6844**	**3617**	**1.7**	**2.6**	**50**	**455**	**33433**

APPENDIX 17. POTATO MECHANICAL SCENARIO

Yield (kg/ha) 22212 / Area (ha) 1.0	Energy (MJ)			Emissions to air (g/ha)									Emissions to water (g/ha)			
	Diesel	Electricity	Total use	CO_2	CO	CH_4	HC	N_2O	NH_3	NO_x	SO_2	C_2H_2	COD	N-tot	P-tot	NO_3^-
Field operations																
1x ploughing	619		619	46700	33		11			530	58					
2x deep cultivation	1092		1092	82400	48		17			900	102					
1x fertilising	17		17	1300	3		1			17	2					
1x planting	353		353	26600	16		6			291	33					
x ridging + weed 2harrowing	602		602	45500	34		13			470	56					
9.3x spraying (pesticides)	447		447	26970	25		9			279	42					
1x harvest	1763		1763	133200	73		25			1463	165					
Sum	**4894**		**4894**	**362670**	**231**		**82**			**3950**	**458**					
Inputs																
Fertiliser production	664	530	5768	457230	368	564		1184	17	1531	2533	1.50	2.31	44	185	
Transport of fertiliser	28		28	2141	1.9		1			13	0					
Pesticide production	155	96	527	13090	7	0.5		4	0.4	18	46					
Seed production	768	78	1586	111124	81	76	11	364	62	756	398	0.19	0.29	6	50	3683
Electricity production			739	5521	13	34		0.5	0.15	11	9					
Diesel production			391	22779	13	13				202	124			0.46	0.07	
Other emissions																
N from soil								1749	480							29750
P from soil															220	
Transports to/from field	489		489	36267	23		8			395	46					
Sum total	**6998**	**704**	**14421**	**1010822**	**737**	**688**	**102**	**3301**	**559**	**6876**	**3613**	**1.7**	**2.6**	**50**	**455**	**33433**

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