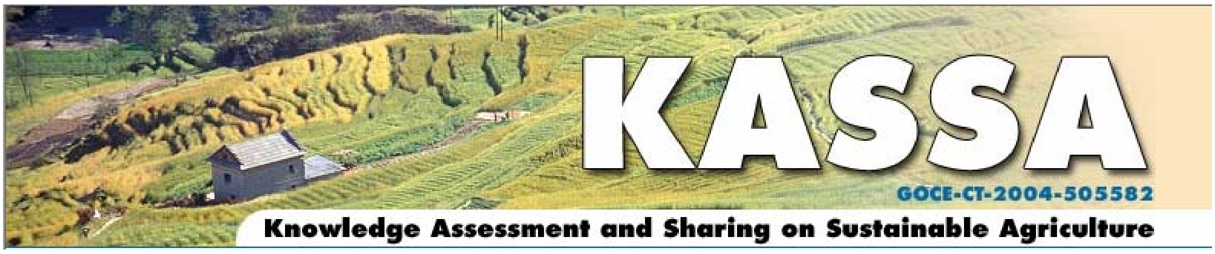

Deliverable 1.1 – Appendix 7

Conservation agriculture in Norway

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Table of contents

1. Context of development of Conservation Agriculture in Norway

1.1 Repartition and evolution

In an effort to improve the sustainability of farming systems in Norway, the agricultural sector has taken two main tracks: Reduced tillage and organic farming. Both of these systems can be considered as conservation agriculture, but with different goals and challenges. Agricultural area represents only 3% of the total land area in Norway, translating into 1,4 million hectares.

1.1.1 Reduced tillage

There are various tillage systems practiced in Norway. They include:

- Conventional tillage: Ploughing in autumn to a normal depth of 18-30 cm, followed by spring seed bed preparation and sowing
- Ploughing in spring followed by spring seed bed preparation and sowing
- Reduced (or shallow) soil tillage: Soil tillage to a maximum depth of 10 cm by means of a cultivator, disc harrow, rotovator or the like in autumn and spring or in spring only
- Direct drilling (or non-tillage): Direct drilling in un-tilled soil where straw has been cut and weeds have been killed by use of chemicals. Most sowing experiments have utilised disc drills.
- Ploughless tillage: Different methods of direct drilling or reduced tillage systems, exclusive of ploughing

Conventional tillage systems lead to a long period during which the soil is highly susceptible to soil erosion and nutrient loss. Soil erosion is an important issue in Norway, especially in the southeastern arable areas of the country. The erosion risk has been assessed on about half of Norway's approximately 0.4 million hectares of arable crop area. Of this, 20% is classified as being at low risk of erosion, 57% has a medium risk, 17% a high risk and 6% an extremely high risk. The erosion risk is particularly associated with autumn ploughing, which renders the soil especially vulnerable during the snowmelt period (Borresen and Riley, 2003). Investigations into the possibility of ploughless tillage systems emerged in the mid-1970's, following the advent of effective herbicides. Growing environmental awareness in recent years has heightened interest in this research area, especially as a result of the North Sea Treaty 1987, which aimed at halving the nutrient losses from agriculture by 1995. In an effort to follow through with this agreement, subsidies were put in place by the government to discourage autumn ploughing and stubble cultivation. In 1991 payments for no autumn tillage were introduced at a rate of 125 euros ha^{-1} irrespective of erosion risk. There was a quick response to the subsidies for no autumn tillage the first years after the introduction of the payment, partially due to the fact that they payment was quite high. There is no doubt that the payments have had an impact, but still more than 50% of the arable land in Norway is ploughed in the autumn. Farmers concerns in abandoning autumn ploughing include lower yields, more weeds and seasonal labour constraints (Lundekvam et al., 2003).

After a few years the government decided to target tillage payments to areas with higher erosion risk. The majority of arable land has been mapped for erosion risk, so it was relatively simple to differentiate payments according to these maps. In 2004 the rates were 48-130 euros ha^{-1} for no autumn tillage depending on erosion risk.

Catch crops have also been supported by the government, not only in an effort to reduce N leaching, but also to maintain soil cover and reduce soil erosion. The areas with no autumn tillage and with catch crops are shown in figure 1. Farmers in Norway also receive payments for light harrowing in the autumn with or without sowing of winter wheat and for direct drilling of winter wheat at a rate of 38 euros ha^{-1} irrespective of erosion risk (Lundekvam et al., 2003).

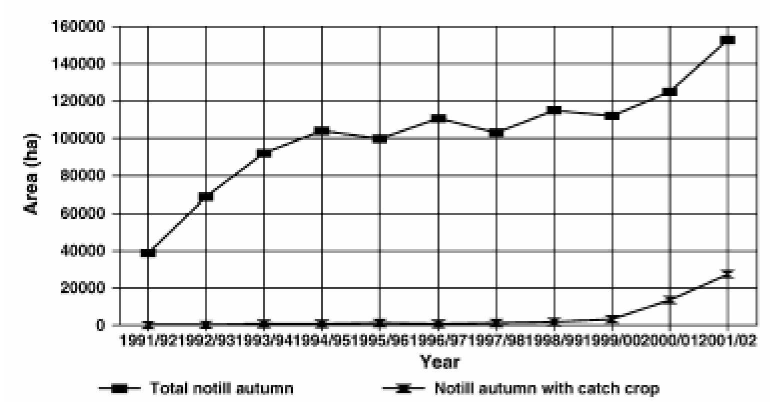

Fig. 1. Total area (ha) receiving subsidies for no tillage in autumn including area with catch crop (Lundekvam et al., 2003).

Table 1: Extension of CA and OF in Norway

	Total area in CA (% of the total land)	**RT**	**NT**	**OF**
Norway	164 000 (16%) (2004)	160000	6000	38000 (3.7%) (2005)

1.1.2 Organic farming

Organic farming emerged in Norway as in many other countries: as a reaction to the environmentally damaging agricultural practices of modern agriculture, such as pesticide and artificial fertilizer usage. As certified production, organic production has been practised in Norway since 1931. Growth on a national scale was slow until the 1990’s, when conversion subsidies were offered to farmers. There are currently 34 957 hectares in organic production, which represents 3.3% of the countries agricultural area (Debio, 2005). Figure 2 shows the increase in the number of organic farms in Norway since 1986. There are currently 58 800 farms in Norway, with 2 484 of these being organically certified. The official Norwegian goal for organic production is to achieve a 10% share of the agricultural land before 2010. In 1998 the government introduced a subsidy to farmers converting to organic agricultural practices. This had a significant effect in increasing the number of organic farms in Norway, as seen in figure 2. Without the conversion subsidy, the farmers faced poorer yields plus regular prices for their products during the conversion process. This was a risk that many farmers were not willing to take. In effect, the conversion subsidy made it much more economically viable to convert to organic farming in Norway. The support of organic farming is mainly due to goals set by the government of less use of pesticides and artificial fertilizer and the environmental and health benefits derived from this type of agricultural system. Norwegian agriculture is also changing from a focus on food production to a focus on multifunctional agriculture. Multifunctional agriculture implies that the valuable products and services produced on the farm are not only food, but include also environmental services, landscape management, tourism etc. These added values of agriculture fit well with the principles of organic farming, and this common goal will be important in the future development and support of organic agriculture in Norway.

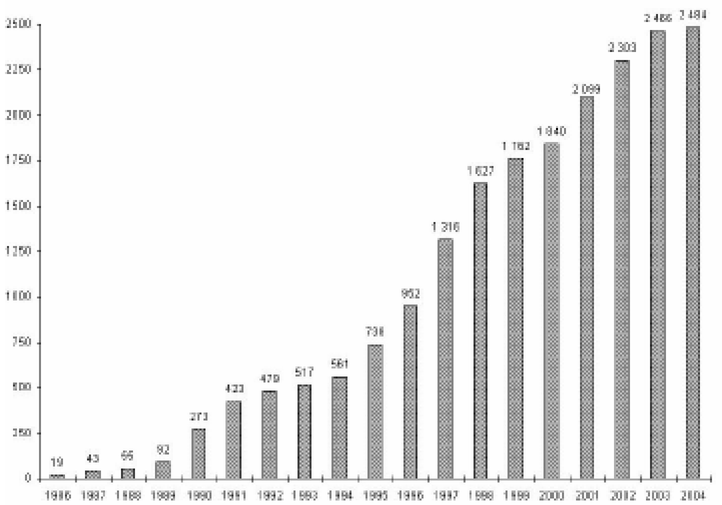

Figure2: Number of organic farms in Norway, from 1986-2004 (Debio, 2005)

1.2. Potential factors inducing evolution

1.2.1 Pedo-climatic conditions:

From an agricultural standpoint, the dominant climatic features of Norway are the shortness of growing season (May to September) and the long period during which the ground is either covered with snow or frozen (November to April) but with frequent thawing periods, especially in recent years. Rainfall deficits are common in early summer in the major arable areas, whereas in late summer and autumn both tillage and harvesting can be hampered by excess rainfall. As such, cropping systems that provide rapid plant establishment are essential, both to ensure the use of spring-available moisture and to avoid harvest losses (quantity and quality) in the autumn. There is generally not enough time to establish autumn-sown crops, except for in the southernmost areas.

Due to long winters and cool growing season temperatures, the speed of mineralisation is much slower than in more southern areas of Europe. As such, loss of soil organic matter and carbon is not as problematic except in limited area with very sandy soil. Much modelling research has therefore focused on nitrogen and phosphorus. The loss of these nutrients is much more of an issue, especially during spring snowmelt and in late autumn, when no plant biomass is available to take up the available nutrients. The cool growing conditions in Norway make no-tillage systems a challenge, as the soil in these systems warms up much more slowly. The cool spring soils can affect germination and increase seed diseases, which can reduce the overall plant establishment. In addition, the cool spring soils slow down the process of mineralisation, resulting in nutrient availability issues.

The topography of Norway adds extra challenges to sustainable production. Many agricultural areas are hilly/mountainous, translating into a high risk of water erosion. As such, much research has been focused on soil erosion reduction.

1.2.2 Economic conditions:

The trend to reduce labour and increase farm scale is also present in Norway. Reduced tillage has been seen as one important way to reduce the need for extra labour, plus manage a larger land area. On the other hand, organic farmers are meeting economic challenges by diversifying their farming systems, for a more stable economic situation. However, they too are looking for ways to reduce labour input, due to the added cost plus the difficulty of finding suitable labour.

1.2.3 Sociologic conditions:

In the 1960's a national agricultural policy was implemented which encourage, through the use of subsidies, specialisation of agriculture production. The goal was to locate cereal production on the best agricultural land with the most favourable climatic condition and animal production in more marginal areas. Following the implementation of this policy, agricultural systems have become more and more divided, with animal production in the hilly/mountainous areas on the west coast, and cereal production in the flatter areas, mainly in Central and South Eastern Norway. This policy has led to a dominance of monoculture cereal cropping systems in the areas best suited to cereal production. As such, issues of soil erosion, weed control, insect control and a heavy reliance on fertiliser have evolved. In the hilly/mountainous areas, the lack of arable crops often provides issues for manure management. The excess nutrients increase the risk of polluting streams, lakes and rivers.

Subsidies act as a strong steering mechanism in Norwegian agriculture. Encouraging practices such as reduced tillage, organic farming, spring tillage and catch crops are practical examples of how the Norwegian government is attempting to improve the sustainability of agriculture.

1.2.4 Agronomic conditions:

Cereals are often grown in monoculture, or in rotation with potatoes, oilseed rape or annual root or forage crops. The proportion of grassland in arable areas is fairly low, as dairy and animal production is mainly concentrated in more marginal areas (see Sociologic conditions). As mentioned, monoculture-cropping systems have raised concerns particularly regarding pesticide usage. In 1990 an action plan was developed by the government, with the goal to reduce the use of pesticides in Norwegian agriculture. This has encouraged research on alternative weed, disease and insect control methods and also early warning and decision support systems for the farmers (VIPS). The goal of reducing pesticides is not however simple in reduced tillage systems. In Norway, straw residues and weed and disease control have been the largest issues when reducing cultivation activities. The Norwegian results confirmed investigations from other countries showing that weeds and diseases can increase and cause a greater dependence on pesticides when tillage is reduced (Torresen et al., 1999). The conflicting goals of reducing erosion and reducing pesticide usage are indeed a challenge for the Norwegian agriculture and hence the research community. To control perennial weeds, more herbicides are used, in particular glyphosate. Even though glyphosate is considered to be an environmentally friendly herbicide, concern of its fate in the soil and water has risen. The Norwegian Crop Research Institute (NCRI) is now ending a research program "Pesticide in the environment" where the binding and degradation of this chemical was an issue. Fusarium diseases and mycotoxin production is another challenge in reduced tillage systems (Henriksen et al., 1999).

For farmers considering converting to organic farming, the option of a stockless system is attractive. In areas best suited to cereal production, there has been little animal husbandry since the 1960's. As such, the farms in these areas often do not have proper facilities for animal husbandry. In addition, the extra labour requirements act as a deterrent to the integration of animals onto the farm. The challenges of stockless organic farming are therefore a current research focus. This work is attempting to develop more stabile and higher yields on stockless organic farms (Eltun, 2005). They are looking specifically at the bottlenecks of weed control, nutrient availability and soil structure. A PhD project based on the holistic management of these issues, in an effort to improve the entire farming system, is also an integrating part of the project.

2. Conditions of obtaining results

2.1 Partners

2.1.1 Research institutes:

- *The Norwegian Crop Research Institute* is the leading institute in Norway for applied research on crop production, and contributes actively to the development of the future of agriculture and horticulture in Norway.
- *The Norwegian Centre for Organic Farming* is an institute who works exclusively with research and development of organic agriculture. Their activities are characterised by the high priority given to direct farmer contact and the search for practical, locally adapted solutions to the individual farmer's problems.
- *The Norwegian Centre for Soil and Environmental Research*, is a national centre of expertise for environmental issues related to soil, water, waste and landscape resources.
- *Norwegian University of Life Sciences (UMB)*: UMB is recognised as a leading international centre of knowledge, focused on higher education and research within environmental- and biosciences.
- *The Norwegian Agricultural Extension Service* has the primary task of giving advice based on locally conducted research regarding all kinds of crop production.

2.1.2 Main experiments in Norway

Field experiments:

Organic farming:

- *The Norwegian Crop Research Institute, Apelsvoll* (Eltun, 1994) (Eltun, 2005)
  One of the most important field experiments in organic farming has been an eight year experiment at Apelsvoll, which included six different cropping systems (Eltun, 1994). They examined soil fertility, economics, yield and environmental aspects, including runoff and leaching, of the different systems (Eltun, 1996a; Eltun, 1996b; Eltun and Fugleberg, 1996; Eltun et al., 1996; Eltun et al., 2002).
- The Norwegian Crop Research Institute, the Plant Protection Centre and The Norwegian Centre for Organic Farming finalised in 2002 a research programme on plant protection in organic vegetable farming. The main focus in the field trial was on mulch as a method to control weeds and pests in row crops.

Reduced tillage:

- *Norwegian University of Life Sciences and The Norwegian Centre for Soil and Environmental Research (Ås) and The Norwegian Crop Research Institute (Nes).*
  Long-term trials (12-27 years) have been performed with various forms of conservation tillage on representative soil types under varying climatic conditions. In 1988 and 1989 tillage trials were respectively established on a poorly-drained silty loam overlying silty clay loam and on a freely-drained sandy loam overlying

medium sand. Autumn and spring ploughing and two ploughless systems were compared for 12-13 years, with three replications at each site. The ploughless treatments comprised deep versus shallow spring harrowing until 1999, and thereafter autumn plus spring harrowing versus spring harrowing only.

- *Norwegian Crop Research Institute (Ås)*
  Long-term field trials were established in the autumn of 1993 and continued through 2000 in the central and South Eastern part of Norway in spring cereals in the county of Akershus, Oppland, Hedmark and Nord-Trøndelag to study the long term effect on grain yield, weeds, diseases, mycotoxins, pests and beneficial insects. Five tillage treatments were performed.

On farm:
- *The Norwegian Agricultural Extension Service* does extensive on-farm research, with the aim of developing more locally suited advice for farmers. They do work in both organic and conventional agriculture.
- *The Norwegian Centre for Organic Farming* conducted an extensive on-farm study of 30 farms (organic and in conversion), from 1989 to 1993 (Kerner, 1994).

Combined field and Laboratory research:
- Modelling: MILDRI project at *UMB (Ås).*
- Some research has also been conducted on allelopathy at *UMB & Norwegian Crop Research Institute (Ås).*
- Pesticide in the environment 2000-2005: *Norwegian Crop Research Institute (Ås), The Norwegian Centre for Soil and Environmental Research (Ås) and UMR INRA INA-PG, Environment et Grandes Cultures Thiverval-Grignon, France*. A part of this programme was to study the effect of climatical conditions on behaviour and fate of the herbicide glyphosate in the soil. The three sites chosen for field studies of pesticide dissipation and transport pattern were situated at N 69^{o}15’ E 18^{o}33’ (North Norway), N60^{o}28’ E 12^{o}02’ (South East Norway) and N 47^{o}40’ E 2^{o}25’ (West France). These sites were comparable agricultural fields of alluvial sandy loam soil, with low organic matter content and low binding capacity, above shallow groundwater table. All experiments were done as laboratory studies of soil sampled from these sites.

3. Significance and impact of the results obtained

3.1 Greenhouse gases emissions

Modelling work in the area of N-enrichment and emissions of N_20 to the atmosphere has taken place at the Norwegian University of Life Sciences. (Bakken and Bleken). Modelling the nitrogen cost of food production in Norway has also been accomplished by these authors (Bleken and Bakken, 1997). This work is not specific to reduced tillage or organic farming, but it gives us insight into the nitrogen utilisation and losses from agricultural systems, which are relevant to organic farming and reduced tillage systems. The nitrogen costs (the ratio between fertiliser N-input, including animal manure, and the N products) is around 3 for wheat, 14 for dairy products and 21 for meat, *indicating that major reductions in the consumption of N can be made by introducing more a vegetarian diet and better utilisation of existing food.* This type of recycling at a higher trophic level was shown to be much more effective than attempts at lower trophic levels, such as composting.

Bleken in cooperation with NCRI, is now currently responsible for a project regarding the effect of climate change on crop production in Norway.

3.2. Land management and risk assessment

MILDRI is an interdisciplinary research programme. It has the main objective to produce knowledge for developing a more environmentally sound forms of agricultural production in Norway. The main focus is on modelling the loss of nutrient and soil erosion together with use of plant protection chemicals. Economic, agronomic and environment analysis is integrated in a simulation model (MILDRI, 2005).

The programme contains seven projects: Integrated System Analysis; Nitrogen Dynamics in Soil; Model Development for Plants; Plant Protection, Animal Manure Management, Soil Erosion Modelling and Policies for a More Environmentally Friendly Agriculture. A collection of models have been used in these projects, including:

- ECECMOD (2.0): Consists of external inputs describing political and economic conditions (scenario dependent), farm characteristics, data on natural conditions (weather, soil, topography). The model consists of 8 process based models
    - FARMNOR: Integrate choices of agronomic practices, prices, environmental regulation and subsidies into the scenarios.
    - PVNOR: This dynamic model simulates the development of weeds and diseases at different scenarios of soil tillage, the need for plant protection measures and the resulting effect on crop yield
    - FIELDVOL: Predicts ammonia volatilisation, based on management, fertilisation, soil properties, plant cover and climate.
    - KONOR: A cereal crop modelling, which is a dynamic plant model, based on plant growth and N uptake of plants. It is closely linked to the SOIL and SOIL_NO models.
    - SOIL: A hydrology and soil temperature model
    - ENGNOR: A ley crop modelling, which is a dynamic plant model, based on plant growth and N uptake of plants. It is closely linked to the SOIL and SOIL_NO models.
    - SOIL_NO: Models soil N dynamics and nitrogen leaching, based on temperature, moisture, evaporanspiration, N and C balance in the soil, mineralisation of organic material, denitrification and plant-available N. This model is closely linked with the SOIL model, and KONOR and ENGNOR models.
    - ERONOR: Estimates soil erosion and P losses, based on soil erodability, slope steepness, slope length, snowcover, runoff, precipitation, soil saturation, plant cover and residue cover, consolidation and some structural effects, climate and management

The MILDRI project was expected to be very important in Norway as a tool for improving land management and identifying high-risk practices. *The models linked together are expected to be a tool for the agricultural authorities to direct subsidies most effectively for the betterment of the environment.* So far the government does not exploit the model system properly and there are examples of subsidies that are not targeted enough. The models can be used to evaluate both organic farming systems and reduced tillage systems, and as such can be useful in decision-making processes. Results of the MILDRI project will follow throughout this report.

3.3 Water pollution and soil erosion

3.3.1 Nutrient leaching

As mentioned in the introduction, the combination of a short growing season in Norway, wet autumns and spring snowmelt give a high risk for nutrient leaching. As such, many authors have investigated the nitrogen dynamics of farming systems, in an effort to identify practices that can reduce losses and improve availability during the growing. Korsæth et al., (2002a) used field experiments and the SOILN_NO model to investigate the N dynamics after incorporation of a mixture of a green manure material (undersown white clover) and barley straw. The work showed that spring incorporation of undersown clover gives a better coincidence of N availability and N uptake by a subsequent crop than does autumn incorporation. However the modelling scenarios showed that ploughing as late as possible in the autumn appears to be a good alternative to spring ploughing, with regards to N leaching. It was very clearly shown that early autumn ploughing should be avoided. Korsæth et al., (2003) also investigated the N dynamics of grass as affected by N input regimes, soil texture and climate. They utilised lysimeter measurements and two dynamic simulation models (CoupModel and SOILN_NO) and the work clearly illustrated that low nitrate leaching from the system can be mainly attributed to a high plant N uptake. *As such, this work illustrates the importance of plant cover year round.*

A fundamental goal in organic agriculture is to farm in an ecologically sustainable way by aiming at self-sustaining systems based on local and renewable resources. The shortage of animal manure and small demand for roughage feed in southeast Norway along with restrictions on the use of organic household waste[1] and prohibition of sewage sludge in organic farming (Debio, 2005) make green manures the most possible manuring and soil fertility-building solution on stockless organic cropping systems. The release of inorganic N from green manures is highly dependent on their biochemical quality and on environmental factors, primarily temperature and moisture. *Therefore, it is a major challenge to synchronise the release of N available to plants with their demand and thus ensure adequate crop yields and minimise the risk of environmentally harmful effects owing to nitrogen losses*.

Generally, organic farms have a lower risk of nitrogen leaching due to lower stocking rates, lower total input of N and greater use of catch crops in autumn and winter (Hansen et al., 2001; Korsaeth and Eltun, 2000). However, problems can occur when ploughing at the wrong time, with no subsequent crop to capture the mineralised N (i.e. ploughing in early autumn). Practices such as low self-sufficiency in feed, low crop yield and importing manure can also increase the risk of N leaching on organic farms (ibid). Nitrogen leaching is dependent on many factors, which can be divided into *non-remediable* and *remediable* factors. The farmer has to adapt to the non-remediable factors, which include soil type, topography and climate (precipitation and temperature). However, farmers can control remediable factors, which include: type, timing and amount of nitrogen fertilisation (Bergström, 1987; Bergström and Brink, 1986; Hansen et al., 2000), irrigation (Jenkinson, 1990), soil inorganic N content in early autumn (Bergström and Brink, 1986; Vagstad et al., 1997), crop yield (Vagstad et al., 1997), choice of crop rotation (including cash crops and catch crops) (Breland, 1995; Breland, 1996b; Hansen et al., 2001; Thorup-Kristensen, 1994) and type and timing of cultivation

[1] The user has to document the need for this material. The following list of organic matter is putting the material use in order of priority: Own organic material, bought-in organic material, conventional animal manure, composted household wastes. The composted household waste has to live up to several standards about level of heavy metals and other pollutants and the amount of waste per area is limited Debio. 2005. [Online] www.debio.no..

(Hansen et al., 2000; Korsaeth et al., 2002a; Korsaeth et al., 2002b). These remediable factors are adjustable, and as such play important roles in building creative, new scenarios to improve N utilisation on organic farms.

Matching soil inorganic N supply with crop N requirements on a temporal basis is important to achieve high yield and low environmental degradation. Achieving a balance at an appropriate level between inputs and outputs of nutrients within the farm system is critical to ensure both short-term productivity and long-term sustainability (Watson *et al*., 2002). Norwegian authorities encourage organic grain production and market demand is increasing. *Consequently, there is a need to investigate the potential for negative environmental effects and find out how to possibly reduce these within a systemic context, while recognising that the farmer has to pursue multiple goals simultaneously.*

The importance of nutrient availability during the growing season, and reduction of losses is especially important in organic farming systems. These systems rely on internal supplies of nutrients, and improving the utilisation of this resource has been the focus of many projects (Eltun, 1995; Eltun and Fugleberg, 1996; Korsaeth and Eltun, 2000) investigated the nitrogen mass balances in conventional, integrated and ecological cropping systems, and the relationship between balance calculations and nitrogen runoff in an 8-year field experiment in Norway. Lysimeter readings were taken over a period of 8-years, in six different cropping systems. These included: conventional arable cropping, integrated arable cropping, ecological arable cropping, conventional forage cropping, integrated forage cropping and ecological forage cropping. The N runoff from the systems was in the range of 18-35 kg N ha^{-1}, with the highest losses from the two conventional and lowest from the two ecological systems and integrated forage cropping. The arable systems generally had more runoff than the forage systems.

Solberg (1995) investigated 17 farms in South East Norway, which were either ecological or in the process of converting to ecological farming. For a period of 2-3 years he sampled soil mineral N content and crop N content. The nitrogen leaching potential was estimated from soil nitrate nitrogen content during late October, and was lowest on fields with plant growth in late autumn. On average leaching potential was lowest in leys (6 kg NO_3 ha^{-1}). Undersown grain (13 kg NO_3 ha^{-1}) and green fodder (14 kg NO_3 ha^{-1}) had a low leaching potential. Turnips/vegetables (17 kg NO_3 ha^{-1}), grain without undersown ley (30 kg NO_3 ha^{-1}) and potatoes (33 kg NO_3 ha^{-1}) had a higher leaching potential. Fallow led to a much higher leaching potential (100 kg NO_3 ha^{-1}). Autumn ploughing generally led to a higher nitrogen leaching potential than unploughed soils. A large proportion of legumes in a ley and in green fodder did not correlate with a higher leaching potential.

Most recently, Steinshamn et al. (MILDRI, 2005; 2004) have investigated *the utilisation of nitrogen and phosphorus on an organic prototype dairy farm in Norway*. Nutrient balances and efficiency (N and P in products divided by N or P in inputs) were compared to data from other studies of dairy farm systems in Europe. Despite relatively high nutrient efficiencies at the farm level, there were considerable losses within the farm system. Nutrients were lost during harvesting, storage and feeding of home-grown crops. Thus, the intake of N and P by the herd was on average 62 and 59% of the harvestable N and P in the field crops. The study also highlighted the potential problem of negative soil surface P balance on the long term. *The work suggests that improving forage quality through more frequent cuttings and a moderate concentrate level would increase milk production and improve the N efficiency at the farm level without negative effects on the N utilisation in the animal component.*

The MILDRI models also take into consideration the practice of catch crops to reduce nutrient losses. The use of catch crops have been encouraged by government, and much research has taken place to describe the effectiveness of catch crops in trapping nutrients that would otherwise be leached from the farming system (Molteberg et al., 2004). The undersowing of grasses in cereals has been shown to lower the nitrogen (N) concentration in drainage water and is recommended as a method to reduce N-losses from agricultural fields (Breland, 1995). Several different grass species and varieties have been evaluated under Norwegian climatic conditions, and their ability to drain the soil for inorganic N through vigorous growth in the autumn and their ability to resist winter kill and preserve N from one year to another (Molteberg et al., 2004). Ryegrasses, in particular Italian ryegrass, has shown higher N uptake throughout the growing season than meadow grasses and accumulated 25-35 kg N ha^{-1} in plant biomass if they were well established. Timothy, cocksfoot and meadow fescue accumulated 15-25 kg N ha^{-1}. Winter losses were shown to be higher for ryegrass than for meadow grasses and approximately 20-30% less N was found in the catch crop biomass in the spring than in the autumn. Catch crops reduce soil content of inorganic N from mid-summer until the end of October (Molteberg et al., 2004). Catch crops, such as ryegrass, can pose a certain degree of competition on the main crop. This competition has been shown to result in yield reduction as much as 12% (Molteberg et al., 2004). *The study concluded that the early sowing of Italian ryegrass with a seeding rate of 5-8 kg ha^{-1} resulted in a well-established catch crop that reduces the risk of leaching of N from cereal fields in Norway. Catch crops have also been noted for their ability to reduce soil erosion in addition to reducing N leaching during the winter months* (Breland, 1995).

3.3.2 Pesticides

Pesticides are potential water pollutants. To avoid leaching to surface and ground water it is important to understand the fate of the pesticide in soil. Soil type and pedo-climatic condition strongly influence on binding and degradation of pesticides. The objective of the research programme “Pesticides in the environment” was to gain knowledge on the effect of low temperatures on freeze-thaw activities on degradation of pesticide. The main work was done on glyphosate because this is by far the single most widely used pesticide in Norway (Stenrød et al., 2005a; Stenrød et al., 2005b; Stenrød et al., 2005c; Stenrød et al., 2005d). Glyphosate is periodically recovered from surface water and ground water in Nordic countries. No work has been done which specifically looks at pesticide leaching from reduced tillage systems. However, the advent of reduced tillage has resulted in a substantial increase in the use of glyphosate. *The goal conflict of reduced soil erosion yet increased pesticide usage is an area that scientists in the field of reduced tillage must focus on in the future.*

Results from laboratory experiments support the general assumption of microbial, mainly co-metabolic, degradation of glyphosate in soil. An increase in potential glyphosate degradation activity southward (North Norway < South East Norway < France) both at high (+28°C) and low (+5°C) temperatures was observed. In addition the results indicate a rapid decrease in glyphosate degradation potential with increasing soil depth due to a decrease in soil microbial biomass size (i.e. very low biomass below 50 cm depth).

Results from spraying of glyphosate on two field sites in Norway, show distinct differences in the fate of glyphosate between the sites. After autumn spraying on bare soil in North Norway, glyphosate was found to migrate deep in the soil profile, being recovered down to 80 cm depth the following spring. In contrast, when sprayed after harvest of barley in South East Norway on a surface covered with straw residues, glyphosate was barely detected below 20 cm soil depth the following autumn and spring. Both field sites experience soil frost during winter, with its possible effects on the macropore structure of the soil (i.e. vertical freeze-thaw cracks). The South East site also has a substantial amount of biopores from earthworm activity. Hence, the deep transport of glyphosate in the northern site was probably due to more glyphosate available for downward transport rather than more macropore flow.

Reduced tillage would result in more organic matter in the upper layer and thereby probably better conditions for binding and microbial degradation of glyphosate on the surface and in shallow soil layers. *Theoretically there hence is a possibility that glyphosate not so easily reach surface and ground water in reduced tillage systems as in conventional systems. However, the direct effects of vegetation/straw residues on degradation rate and risk of surface runoff of glyphosate are unclear and require further research.*

3.3.3 Other pollutants

Recycling is a main principle in organic farming. As such, farmers and scientists are working to develop farming systems that recycle both human waste and kitchen waste. However, the current regulations have restrictions on the use of organic household waste and prohibit the use of sewage sludge in organic farming (DEBIO, 2003). One of the main limitations in the recycling of both sewage and organic household waste is risk for contamination of heavy metals. As such, several projects are investigating the challenges of recycling human and kitchen waste back to the farm (Ellingsen, 2005; Jensen, 2005)

3.3.4 Erosion

Spring ploughing is a practice encouraged by the government, in an effort to reduce erosion and nutrient losses. Lundekvam and Skoien (1998) showed that autumn ploughing leads to a high risk of erosion, whereas spring tillage results in little soil loss when the soil is protected by plant residues after the growing season. *In this long-term trial, they found that spring tillage reduced the annual soil losses by 90%, compared to autumn ploughing.*

Borresen and Njos, (1990) found that spring ploughing, reduced soil tillage and direct drilling will protect the soil better against erosion than autumn ploughing. Erosion in Norway occurs mainly during the snowmelt period, in the autumn after harvest and more randomly during summer and winter. Intensive rains during the summer months can cause high erosion rates. In a six year experiment, shallow tillage reduced water erosion by about one half to two thirds in comparison to conventional tillage, although this is still well about erosion level normally measured on grasslands (Njøs and Hove, 1986). However, the soils on which erosion is most severe are also the ones most difficult to manage without ploughing, due to low drainage and high susceptibility to compaction (Riley et al., 1994). Ploughless systems are generally successful on well-drained loam and clay soils under the relatively dry conditions in southeast Norway, but have proved to be more problematic under wetter conditions, especially on silt and sandy soils. Spring ploughing is an option to avoid erosion in autumn and the snow melting period. *Time of ploughing (spring versus autumn) has little effect on crop yields, even on clay soils. Spring ploughing may, however, delay sowing somewhat and less time for seed bed preparation may result in lumpy and bad structured soil (Borresen and Riley, 2003).*

Catch crops have also been supported by the government, not only in an effort to reduce N leaching, but also to maintain soil cover and reduce soil erosion (Breland, 1995).

Other environmentally motivated payments have been introduced by the government, including methods to capture eroded soil in *sedimentation ponds*. The Norwegian Centre for Soil and Environmental Research is conduction this work. Characterising the soil trapped, ensuring effectiveness of the pools and utilisation of the trapped soil are important topics of study (Sveistrup and Braskerud, 2005).

3.4 Biodiversity

3.4.1 Flora

Weed diversity has been a topic of interest, especially in regards to organic farming. Effects of organic farming on the weed seed bank, and on the diversity of flora have been studied (Sjursen, 2001) (Fykse and Waernhus, 1994). Sjursen (2001) investigated the changes in the weed seed bank in the top soil during a six-year period on an organic cropping system. The six-year period included a sequence of annual crops and a perennial grass-clover ley in the rotation. *The study found the lowest levels of dicotyledonous annual species following the 3-year ley, and highest level following the three-year period with annual crops.* The study also found that the soil seed bank and emergence of weed plants was not straightforward, indicating that an increase in the soil seed bank does not always correlate with an increase in weed emergence.

The effect of reduced tillage on the weed flora and week seed bank have also been of interest (Torresen et al., 1999) (Torresen and Skuterud, 2002). Torresen et al., (1999) conducted five long term field trials with reduced or no-tillage. *In this study, they found that weed infestation increased compared to autumn or spring ploughing systems. It was necessary to use glyphosate in the autumn and a post-emergent herbicide in the spring to control weeds sufficiently.* Weather was also shown to play a strong role in weed emergence and growth of weeds. Within the same experiment, more specific observations regarding changes in the weed flora and weed seed bank were made (Torresen and Skuterud, 2002). This work showed that *winter annual, biennial and perennial weed species* increased when tillage was reduced compared to conventional seedbed preparation by ploughing and harrowing. The weed seed bank in the upper soil layer increased when tillage was reduced. However, if weeds were controlled, no changes in the seed bank occurred. The study also highlighted that perennial weed species with mainly vegetative propagation with roots and rhizomes were a problem in reduced tillage. The most frequent species are *Elymus repens*, *Cirsium arvénse* and *Sonchus arvensis*.

3.4.2 Fauna

Beneficial arthropods such as spiders, staphylinidae and carabidae have been the focus of much research. Much of the focus has been on how these arthropods react to organic farming systems (Andersen and Eltun, 2000; Haraldsen et al., 1994; Pommeresche, 2002) and reduced tillage (Andersen, 1999; Andersen, 2003).

In two field experiments over periods of 6-8 years, the activity and density of carabids and staphylinids was measured during the conversion from conventional to organic farming (Andersen and Eltun, 2000). The study showed a positive effect for many carabid species, including *Harpalus rufipes* and several *Amara*, *Bembidion* and *Pterostichus* species. The conversion was also positive for the population of the staphylinid fly parasitoid *Aleochara bepustulata*. *The main explanation for the rise in these species was the increase in weed species.* There were however negative effects from the conversion on several carabid and staphylinid species, and it was hypothesised that this could partly be due to competition from the rising number of carabids. Spiders are also an important beneficial arthropod, and were the focus of a study conducted in two organically managed leys in different stages of a crop rotation and in one permanent pasture (Pommeresche, 2002). 48 species were found in this work, with fewer species in the younger ley, and more species in the older ley. The maximum number of species was found in the permanent pasture.

Andersen (1999) conducted five field experiments run for four years to compare the activity of carabids and staphylinids in autumn ploughed and reduced tillage (no-tillage or spring harrowed) plots. Weed cover was denser in reduced tillage, and explains much of the results. Generally, more carabids and staphylinids were caught in reduced tillage. This was especially true for *Amara* species and *Loricera pilicornis*, *Philonthus cognatus* and *Tachinus signatus*, which are were also positively correlated with weed cover. In another article Andersen (2003) reports the results of the three years following the first paper (Andersen, 1999). Herbicide treatments were added in the last 3 years, leading to fewer differences in the activity of carabids and staphylinids in autumn ploughed and reduced tillage (no-tillage or spring harrowed) plots. *This indicates that the weed cover was a more important factor than the tillage treatment*. However, there were still generally more carabids caught in the reduced tillage plots.

The importance of earthworms in building and improving soil structure has been focused on by several authors (Pommeresche and Meisingset, 2005) (Sveistrup et al., 1997). Work has also been conducted to investigate the effect of earthworms during the conversion from conventional to organic farming in Norway (Haraldsen et al., 1994). The main goal of the study was to analyse the earthworm species present, but the study also showed that plant roots only grew beneath the plough zone when they could grow through earthworm channels. This is an important example of how earthworms can help to improve the soil structure.

Other authors have looked more specifically at factors such as field boundaries (Dennis et al., 1994; Frampton et al., 1995) and flower resources (Dramstad and Fry, 1995) on the activity and dispersal of beneficial arthropods. For example, Dennis et al., (1994) found that a the winter survival of carabids and staphylinids was the lowest on bare earth and highest in areas of tussocks of Dactylis glomerata. *They showed that proper overwintering sites are important for beneficial arthropods, but other factors such as pre-winter husbandry, food supply and parasitism may affect the dispersal power, habitat selection and cold hardiness of beneficial arthropod species.*

3.5 Agronomic impact

3.5.1 Physical properties

The importance of compaction in organic farming has also been recognised for sometime. Hansen (1996) evaluated the effect of soil compaction on a dairy farming system during conversion from conventional to organic farming. The author found that soil compaction by tractor traffic decreased the average dry matter yields in ley from 9.0 to 6.6 ha^{-1} $year^{-1}$. The study showed that compaction had a stronger influence on yield than either manure treatment method or nutrient level. *The soil compaction led to a reduction in the air-filled pore space from 12-7% and reduced the number and mass of earthworms.* This study has highlighted the importance of avoiding compaction, which is now one of the topics of an on-going project based on the challenges of stockless organic systems (Eltun, 2005). Within the project aimed at stabilising and increasing yields on stockless organic farms (Eltun, 2005), one of the key areas of focus is soil structure. More specifically, how tractor weight, plough depth and way of driving affect soil structure will be investigated (Bakken et al., 2005).

Several studies have also considered the yield changes when converting from conventional farming to organic farming. Results from the 30 farm project (Kerner, 1994) showed that grain yields were on average 20-25% lower than conventional yields. In the 8-year experiment at Apelsvoll, yield reduction experienced with integrated and ecological cropping, relative to conventional cropping, was smaller for forage crops and potatoes than for cereals (Eltun et al., 2002). *This work suggested therefore that it is easier to maintain the yield level by reduced crop intensity in mixed farming systems with livestock than in arable farming systems without livestock.*

Several authors have investigated the effect of reduced tillage on the soil physical properties and soil quality (Ekeberg and Riley, 1997) (Riley et al., 1994) (Borresen and Njos, 1994). A Scandinavian review article of reduced tillage gives an overview of the impacts of reduced tillage on soil physical properties (Rasmussen, 1999). One of the clearest effects of ploughless tillage is the increased density of the soil just beneath the depth of tillage. The increase in soil density has shown to decrease the volume of macropores (>30-60 µm) and increased the volume of medium pores (30-0.2 µm), but the volume of small pores (<0.2 µm) was only slightly affected by soil tillage. The increased bulk density of reduced tillage soils also has been shown to reduce the air-filled porosity, the air diffusivity and the air permeability as well as the hydraulic conductivity, and sometimes root development. In addition, reduced tillage systems tend to accumulate plant residue on or near the soil surface, which leads to lower evapotranspiration and higher content of soil water in the upper (0-10 cm) soil layer. This is an issue in Norway, with its short growing season, as wet soils result in later seeding and cooler soils. The effective shortening of the growing season can have both quality and yield costs. *The success of reduced tillage has been shown to depend on the crop grown, the preceding crop and the soil type (Rasmussen, 1999).*

Crop yields in reduced tillage systems are generally well over 90% of that achieved in conventional tillage (Rasmussen, 1999), when the stubble is treated with glyphosate and a post-emergence weed control in the crop are used (Torresen et al., 1999). When taking into account the potential saving on labour, fuel and machinery, reduced tillage will give a net benefit (Riley et al., 1994). Both on poorly-drained silty loam and on a freely-drained sandy loam increases in penetrometer resistance occurred in the topsoil of unploughed treatments. These were considered particularly limiting on the sandy loam. On the silty loam there was an increase in surface horizon porosity in the absence of ploughing, which was associated with an increase in topsoil organic matter content. On this soil there was also a tendency toward lower penetrometer resistance at > 30 cm depth on autumn plus spring harrowed soil than on ploughed soil, indicating that the plough pan may have diminished. This was supported by observations of greater earthworm activity on unploughed soil (Riley et al., 2005).

3.5.2 Soil Chemical properties

The fertiliser requirements of conventional tillage systems, compared to reduced tillage systems are of interest in Norway (Riley, 1998). The changes in the tillage systems affect the moisture, temperature and residue placement and hence the mineralisation of the soils. Finding out how to most efficiently fertilise in a reduced tillage system is important knowledge for farmers. It could be expected that more nitrogen would be required in order to compensate for any sub optimal physical or biological conditions resulting from ploughless tillage. On the other hand, over the long term, fertiliser requirements may even be expected to decline as a result of accumulation and mineralisation of organic mater. *Fairly similar nitrogen fertiliser response curves have been found in ploughed and unploughed soils (Riley et al., 1994; Riley, 1998)*. Riley (1998) found that the soil mineral nitrogen levels prior to fertilisation in the spring were on average 8% lower with reduced tillage than with conventional tillage. The author also found that plant development was delayed in reduced tillage, but this was compensated for later in the season. *On the basis of this work, it was concluded that long-term reduced tillage does not affect the N-fertiliser requirements of spring cereals on loam soils under cool climatic conditions.* Soil chemical analyses have revealed that mineral N and plant-available P and K accumulated in the upper horizon under ploughless tillage.

3.5.3 Crop yields

Long-term trials have shown that yield levels can be maintained over time with reduced tillage, provided one is able to meet the challenges of weed control, straw management etc. *There are, however, large annual variations in the yield responses with such systems, in both positive and negative directions.* It may be reasoned that this is due to interactions between weather conditions and the changes in soil structure that occur when ploughing is omitted. The poorest result have been found on poorly-drained soil.

The percentage yields obtained in individual years with autumn as opposed to spring ploughing, were positively correlated with air temperature during 0-4 weeks after planting on the silty loam, and with precipitation during 0-12 weeks after planting on the sandy loam. In the case of yields obtained with spring harrowing only, relative to spring ploughing, positive correlations were found with 0-4 week temperature on both soil types, *suggesting that low early-season temperatures may limit yields under ploughless tillage.*

Results from trials showed a positive relative yield development with reduced tillage in the mid-nineties (Riley et al., 1998). In this period there were several years with pronounced drought in South East Norway, which may account in part for this development. The next four years, on the other hand, were characterised by varying degrees of drought during germination, followed by higher than usual rainfall and cool weather during the growing season. This led in some cases to less favourable results with reduced tillage systems (Riley et al., 2002).

In general terms*, the trials show that long-term yield levels without ploughing but with autumn harrowing, are seldom below 95% of that obtained with annual ploughing.* Spring harrowing alone may in periods give yield levels below 90% of that obtained with ploughing, but in the long term this method probably has a yield potential of 90-95%.

Yield losses with direct drilling are likely to be somewhat higher, especially when the method is practiced under unsuitable conditions, with excessive amounts of straw or on poorly-drained soils. Direct drilling has in trials on clay soil normally led to yield reductions of up to 20%. *The method has been more successful with winter wheat than with spring-sown crops, and has proved unsuitable when there are large amounts of crop residue (straw) on the soil surface.*

3.5.4 Weed management

Learning to deal with new weed situations in reduced tillage and direct sowing systems is a challenge for both farmers and researchers. Much work has been focused on identifying the changes that occur when shifting to reduced tillage farming (Skuterud et al., 1996) (Torresen et al., 1999) (Torresen and Skuterud, 2002) (Ekeberg, 1992). These results were dealt with in the section regarding flora. However it can be summarised that to maintain sufficient yield levels, sufficient weed control must be achieved.

- *Spraying in the stubble against perennial weeds with glyphosate is necessary*, either in autumn or in spring, normally at 1-2 year intervals, as well as ‘normal’ herbicide control of annual weeds with selective herbicides.
- *Large amounts of annual meadow grass (Poa annua) germinate in wet years in the absence of ploughing.* Although this may not affect yields at first, these weeds must be controlled before the next crop is planted or with a selective post-emergent herbicide in the crop.

The heavy reliance on herbicide usage in the reduced tillage system is a concern, and warrants further study.

In organic farming, there is a strong focus on utilising many different methods of weed control, such as crop rotation, ploughing, harrowing, flaming, and mulches. The use of a cover crop, e.g. a legume living mulch in association with an annual or perennial crop, is one possibility for increasing agroecosystem diversity. Cover crops enhance the functional diversity of the agroecosystem and exploit otherwise empty niches. The potential benefits of cover crops include improved soil structure and water penetration (Karlen et al., 1994), decreased soil erosion (Rüttimann et al., 1995), increased soil microbial and faunal activity (Garibay et al., 1997), better supply of plant-available nitrogen (Breland, 1996a), and improved soil fertility and crop yields (Brandsaeter et al., 1998; Breland, 1995). Cover crops can also reduce insect damage and promote beneficial insects (Risch et al., 1983).

Reduced weed competition is another benefit of a living mulch system, as the cover crop fills niches normally populated with weeds. The effect of cover cropping systems suppressing weed populations has been shown in numerous studies (Brandsaeter et al., 1998; Breland, 1996a). Early season ground cover and resource exploitation appears to be very important in controlling weeds in late summer (Brandsaeter, 1996). Therefore the over wintering of cover crops is quite important. Living mulches have also been shown to have superior weed control compared to dead plant mulch.

From an anthropocentric point of view, not all qualities of a living mulch system are positive. In order to provide a habitat for beneficial arthropods, ward off harmful insects, and compete with weeds, the living mulch generally also competes with the main crop for space, moisture, nutrients and light. The agroecosystem loses productivity, as does a mature ecosystem. One non-chemical way to avoid or decrease the competition in such systems is to combine a main crop and a cover crop that have maximum vegetative growth at different times Subterranean clover has a promising life cycle for use as a living mulch, however, winter-hardy cultivars suited for Nordic conditions have not been found (Brandsaeter and Netland, 1999; Brandsaeter et al., 2000; Brandsaeter et al., 2002). Another method to reduce the interspecific competition between the cover crop and the main crop is to mechanically manage the growth of the cover crop. Brandsæter et al., (1998) found that mechanical suppression of white clover and subterranean clover living mulches in white cabbage reduced interference. A third way to reduce competition is to use tall winter annual or biennial species with sufficient winter hardiness, such as hairy vetch or yellow sweet clover, sown in the autumn or early summer the year before, respectively, and mowing them into a mulch prior to transplanting the crop.

Incorporation of the living mulch results in a release of more soil inorganic nitrogen throughout the plough zone, compared to systems without mulch. This may have a positive effect on crop growth, especially in organic systems where plant-available nutrients may be limiting. However, frequent tillage is a disadvantage because only short-season annual plants can be used, and the soil is exposed for much of the year. Brandsæter et al.(1998) found that rototilling the cover crops was more effective than mowing in the suppression of weeds. Cover crop combined with rototilling reduced weed biomass by 89% compared to the monoculture.

Even though yield is generally reduced in living mulch systems, there are often quality improvements that may compensate economically for the yield loss. *Brandsæter et al. (1998) found that both subterranean clover and white clover living mulches gave significantly more marketable cabbage heads than monoculture due to less insect damage, without the use of insecticides.* Even so, efforts should be made to reduce interference so that yield losses are minimized, while maintaining a balance of insect and weed control. Further research work is needed to make these methods robust and competitive to mechanical weeding in row crops. Screening for more winter and biannual species with sufficient winter hardiness could be successful.

3.5.5 Disease management

Farmers and researchers have also been interested in the changes in disease occurrence that take place when shifting to reduced tillage (Elen, 2003) (Elen, 2002). This is an area of much concern globally, and is considered by many to be a major issue in reduced tillage systems. In a study conducted in Norway, the effects of reduced tillage and fungicide treatment on disease development were studied (Elen, 2003). The results showed a continuous increase of *Rhynchosporium secalis* and *Stagonospora avenae* over three years when barley and oats were grown in succession. *The study also showed that ploughing generally reduced the diseases to a low level, and that no tillage treatments of oats had a heavier disease incidence than autumn ploughing. The study also emphasised the importance of crop rotations in reduced tillage systems, to reduce disease problems.* They showed that S. avenae levels were reduced by at least 17 times from one growing season to the next after one year's interruption with a non-host crop. It is evident that no ploughing, in combination with monoculture, increased the incidence of soil borne leaf spot diseases and hence more care has to be taken in choosing crop rotation if excess fungicide treatments should be avoided.

Mycotoxins

The level of *Fusarium* infection and trichothecene content in cereal grains were studied under no-tillage, spring- and autumn harrowing, and spring- and autumn ploughing in five fixed field trials in different Norwegian districts during the years through 1994-2000. Effects of tillage treatments on *Fusarium* and mycotoxin contamination varied between fields and years. When all years were analysed together, significant effect of tillage method was observed for two fields. The effects were consistent, with reduced tillage (harrowing or no-tillage) increasing the level of *Fusarium* contaminated grain in the samples compared to autumn ploughing. The same effect was observed in two of the other fields in 1998 and 2000. Low levels of DON were detected during the experimental period, which was consistent with the low number of the DON-producing species *F. culmorum* and *F. graminearum*. Nivalenol, fusarenon-X, and 3-acetyl-DON were not detected in any samples. HT-2 was detected in most of the samples analysed in 1997 and 1999. The level of HT-2 toxin was consistently higher in harrowed and no-tilled plots than in ploughed plots for all fields. The mean level of *Fusarium* contamination and mycotoxin content in each field, were mainly correlated with climatic conditions in the area. Precipitation during the flowering period significantly explained the differences in level of contaminated grains. Differences between tillage treatments (spring harrowing, direct drilling and autumn ploughing,) were mainly detected in years with moderate to high levels of precipitation during flowering and levels of *Fusarium* contaminated grains between 30%-80%. Differences between tillage treatments were rarely detected in very dry fields/years and low levels of *Fusarium* contamination (less than 30%), as well as in very wet fields with very high *Fusarium* contamination (above 80%). Soil type did not have a direct effect on *Fusarium* contamination level in the fields, but may have had an indirect effect through affecting the general moisture content in the field and the plant stand (Henriksen et al., 1999).

It can be concluded that Fusarium and mycotoxin production can be a major challenge ploughless cereal production in Norway.

3.5.6 Pest management

The mandate to reduce pesticide usage in Norway has opened up the research field of alternative pest control. Beneficial arthropods are one area of interest. The effect of reduced tillage systems on both pest and beneficial arthropods has been reported (Andersen, 1999) (Andersen, 2003) and is summarised in the fauna section. Anderson (1991) has also been active in mapping the presence of carabidae and staphylinidae in agricultural fields.
As described in the weed control section, Brandsæter et al. (1998) have tried an alternative approach to controlling pests in vegetable systems. They have researched the effect a cabbage-living mulch system on the yield, weeds, pest damage and soil nitrogen. *The study showed that both subclover and white clover living mulches gave significantly more marketable cabbage heads than monoculture cabbage due to less insect damage.* Their work also highlighted the importance of having multiple criteria when developing improved systems: ie. Insect control and weed control, without significant yield costs.

In organic farming systems especially, there is a need to develop crop protection methods to deal with pest attacks. This is particularly needed in vegetable production. Several studies have investigated the use of Neem seed extracts for controlling caterpillars attacking cabbage (Meadow and Seljasen, 1999; Meadow and Seljasen, 2000). The study showed promising results in the laboratory, in which the neem extracts were used against larvae of *Mamestra brassicae*, *Plutella xylostella*, *Pieris rapae* and *P. brassicae*. The study showed that neem works as both an insect growth regulator and as a repellent that can reduce oviposition.

Others have examined biological control of the pests, *Delia radicum* and *Delia floris*, with a pathogenic fungi (Klingen et al., 2000; Klingen et al., 2002a; Klingen et al., 2002b; Klingen et al., 2002c) . A survey of this insect pathogenic fungi was made in arable fields and adjacent field margins on conventional and organic farms (Klingen et al., 2002a). The study found more insect pathogens in organically managed fields than in conventionally managed fields. In a preceding study, Klingen et al., (2000) used a trap to collect live adults *of Delia radicum* (L.) and *Delia floralis* (Fallén) to observe the presence of the insect pathogenic fungi *Entomoshthora muscae* (Cohn) Fresenius and *Strongwellsea castrans* Batko & Weiser. The fungus *E. muscae* was relatively lethal in adult populations of *D. radicum* and *D. floris*. The fungus caused total infection level of 17.9% in 1996 and 47.7% in 1997. *This method of control is promising, especially when combined with other control methods such as boundary netting.*

3.5.7 Crop residues management

The issue of straw management in reduced tillage systems has been investigated in Norway. Borresen (1999) looked at different methods of straw management, and the effect of the management on yield and aggregate stability. Borresen (1999) found that normal and double amounts of chopped straw residues, on the soil surface increased the mean grain yields during the experimental period (1991-1996) by 0.290 Mg ha^{-1} compared to the other straw treatments. These treatments included burning, removing, shallow incorporation and deep incorporation of the straw. However, in a year with far more rainfall than normal, the grain yield was reduced in the chopped straw treatments, compared to the other treatments. This was most likely due to the reduction in evaporation. Aggregate stability increased in the plots with chopped straw residues. *This study indicated that shallow tillage and direct drilling in combination with a high amount of chopped straw can be used for spring-grown cereals in Norway, without any significant reduction in crop production.*

3.6 Socio-economic impacts

Few projects conducted by the authors focused on in this report have had the goal to directly investigate the social-economic system. However, it is commonplace that the economic and labour impacts of new alternatives are considered and discussed.

The models used in the MILDRI project take into account economical considerations as well as labour requirements. In this way, new scenarios can be judged not only based on their predicted production and environmental impacts, but also on income and costs. The reduced costs for machinery, labour and fuel in reduced tillage systems have been the main factors encouraging the adoption of this management system. From the research it is concluded that the reduced tillage systems studied are sustainable in terms of productivity, relative to labour, machinery and energy inputs.

Organic farmers on the other hand, are often faced with high labour costs, as the time spent on soil preparation, weed control and pest control is often much higher than in conventional farming. Because organic farmers have lower input costs, they can often cope with the higher labour costs, but finding skilled workers is often the limiting factor. Also getting a higher price for their products than the conventional framers is of major significance.
A recent report regarding research on organic farming and the organic food system concluded that the majority of research in this field has been focussed on the farming system: ie agronomic issues (Fossum et al., 2004). They see now the need to focus more on the needs of consumers, product development and marketing, in order to bring the organic movement forward in Norway

4. Discussion and propositions

It is concluded that the reduced tillage systems studied are sustainable in terms of erosion prevention, productivity, relative to labour, machinery and energy inputs. Likely benefits of such systems include higher levels of organic matter and aggregate stability in surface soil horizons. *These advantages yet conflict with increased pesticide usage and this is an area that research in the field of reduced tillage must focus on in the future.* Tied to the goal of reducing pesticide usage is developing weed control alternatives for reduced tillage systems. However it would help if the transport of glyphosate and pesticides in general is less likely in reduced tillage systems than in systems with ploughing. *More research is needed to clarify this hypothesis.*

In Norway the importance of crop rotations in avoiding soil borne diseases is recognised, but more research is warranted to gain a better understanding of this issue in reduced tillage systems. Since it is not reduced tillage as such which encourages the production of mycotoxin from Fusarium, but the combination with climatic conditions, *it will be an issue for research to forecast when conditions for Fusarium growth is favourable.*

There is also a need for more knowledge about the benefits of biodiversity, within field and surrounding the field. There has been little focus on this, as Norwegian agriculture has relatively small fields and is generally surrounded by large natural areas. However, monoculture cereal cropping systems can dominate in the southeastern parts of the country.

Our recommendations are in agreement with those of a report produced in 2004 regarding the future priorities for organic farming research (Fossum et al., 2004). We see the need for research in the area of sustainability and ecosystem services, which encompasses multifunctional agriculture, social sustainability and recycling technologies. T*here are however agronomic issues that still need a considerable amount of focus, including nutrient availability on organic farms, plant health, weed control (in particular perennial weed) and designing productive and stable organic production systems.*

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