Soil organic matter management across the EU best practices, constraints and trade-offs
Annex II Case Studies

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Final Report for:

**European Commission, DG Environment**

**Soil organic matter management across the EU – best practices, constraints and trade-offs**

**Annex II Case Studies**

**Lead:**
VITO (Belgium)

Study accomplished in collaboration with:
BIOIS (France) and RIKS (the Netherlands)

October 2011
Citation and disclaimer

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CASE STUDY 1. THE EFFECT OF LONG TERM CROP ROTATIONS ON SOIL ORGANIC MATTER STATUS IN NORTH EASTERN ITALY

Background information

Location: Legnaro, Veneto Region, North East Italy - Experimental Farm of Padova University

Biogeographical region: Defined as sub-humid- annual rainfall are about 850 mm/y

Time: from 1962 to present (data used 1974 until 2001)

Initiator: University of Padova, Italy

Objectives: To assess the dynamics of soil organic matter and soil properties (chemical, biological) depending on management and environmental variables.

Bibliography:

Key experts: Prof. Luigi Giardini, luigi.giardini@unipd.it
1.1 Context and aims of the case study

Crop rotation is a planned sequence of cultivated crops, grown on the same field. The aim of the crop rotation practice is to promote soil fertility and minimise the development of pests, disease and weeds. Common rotations last between 2 and 4 years (short rotations) and long rotations last between 5 and 10 years (mainly organic agriculture) (BIO, 2010). The case study focuses on the observations made during a long term experiment carried out by the University of Padova. Different soil management regimes have been used, including the practice of crop rotation. The present case study focuses on the findings of the crop rotation trials, and the effects of crop rotation on soil organic matter.

1.2 The Best Practice management method

Two long-term crop rotation experiments have been conducted for over 40 years since 1962 (Lugato et al., 2007). The local climate is sub-humid, with annual rainfall of about 850 mm and temperatures vary on average from 1.5°C to 27.2°C. The soil at the site is a Fluvi-Calcaric Cambisol (as defined by FAO-UNESCO, 1990) with a sandy or silt loam texture and slightly basic pH. In 1962 the SOC content of the soil was 49.2 t C ha, and the C/N ratio 12 and was managed with manure applications and lay cropping with alfalfa. At the beginning of the assessed period (1974), the soil had a C/N ratio of 7.3, and a SOC content in the top layer of 36.1 t C ha (or 1.2 %).

In the experimental field, the soil tillage used is autumn ploughing at 30–35 cm, followed by standard seedbed preparations. The treatments involve the following rotations:

- 6-year rotation included the sequences Maize, Sugar beet, Maize, Wheat, and two years of Alfalfa;
- 4-year rotation included the sequences Sugar beet, Maize, Wheat, Maize;
- 2-year rotation included Maize and Wheat; and,
- 1-year rotation included continuous maize (monoculture).

The experimental layout was a split plot with three replications on plots of 7.8 x 6 m, with the intensification level as the split factor. Experimental treatments including intensification levels are defined in Table 1.
Table 1  Experimental treatments, intensification levels

<table>
<thead>
<tr>
<th>Rotation cycle</th>
<th>High input (HI)</th>
<th>Low input (LI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6-year</td>
<td>4-year</td>
</tr>
<tr>
<td>Crop</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Residue incorporation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Irrigation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Organic inputs</td>
<td>Slurry (t ha⁻¹)</td>
<td>0</td>
</tr>
<tr>
<td>FYM (t ha⁻¹)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Crop</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Residue incorporation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Irrigation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Organic inputs</td>
<td>Slurry (t ha⁻¹)</td>
<td>0</td>
</tr>
<tr>
<td>FYM (t ha⁻¹)</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Crop</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Residue incorporation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Irrigation</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Organic inputs</td>
<td>Slurry (t ha⁻¹)</td>
<td>40</td>
</tr>
<tr>
<td>FYM (t ha⁻¹)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

A publication by Morari et al. (2006), based on data on soil C changes in the long term trials in Padova, suggests that the longest rotations, in combination with high levels (e.g. 20 tonnes per hectare) of organic fertiliser input, had the most beneficial effect on SOM levels. Figure 1 illustrates the results for the part of the trial with high level of management intensity (irrigation, C fertilizing). In the 0–30 cm soil layer an average long-term decline was evident from 36.1 (1974), to 34.6 (1994) and finally to 32.8 tonnes of C per hectare in 2000. The yearly average depletion was 0.12 tonnes of C per hectare. The SOC content, however, tended to be higher in the 6-year rotation, with application of organic fertilizers. This effect may be due to the presence of alfalfa in the rotation, which requires less soil tillage and usually leaves more below-ground organic residues compared to other cereals and grain crops. The smallest C content followed low-input maize monoculture. Also, the C:N ratio decreased from 12 in 1962 to 7.3 in 1974 depending on conditions favoring mineralization. The ratio did not alter significantly from 1974 to 2000.

The analysis of the results of 40 years of trials has highlighted the important decrease in SOC after the introduction of intensive soil cultivation. This confirms a fall in soil quality and a contribution to global CO₂ emissions frequently reported for intensive arable farming (Lugato et al 2007). There are several reasons for this change in soil C levels after introduction of agricultural practices. Organic matter decomposition (and changed chemical status of soil C) is influenced by factors such as climate, quality of crop residues and soil disturbance (e.g. tillage). Soil C may thus be lost from the soil by crop removal or through leaking via air, water or particulate matter. The soil C balance will also be affected by the input of organic matter fertilizer. In Figure 1, there is a decline in soil C during the last 4 years of the study, which can be interpreted as an effect of a change in fertilizer from farm yard manure to slurry, see Figure 1.
As a conclusion, a longer and more complex rotation (an improved crop rotation) with the addition of farm yard manure will have beneficial effects on the SOM levels compared to shorter rotations or monoculture. In the low-input 6-year rotation and in the high-input rotations receiving organic manures soil C was maintained relatively constant over time as the natural decrease of SOM with cultivation was counteracted, (see Figure 1). Monoculture, as well as shorter rotations resulted in a significant loss of C, and thus had a negative effect on the SOM status.

**Figure 1  Soil organic carbon change from 1974 to 2000 based on data from Morari et al (2006)**

### 1.3 Best Practice Trade-offs

The practice of crop rotation was developed in prehistoric times. Greek and Roman authors of the Antiquity already mention a yield decreasing effect, as a result of the cultivation of cereals on the same field year after year, as well as a beneficial effect of legumes on the performance of crops that were cultivated on the same field after the legume harvest (Gyuricza, 2006). Nowadays a large variety of crop rotations exist throughout Europe, however with variable frequencies of use.
In the modern agriculture of today, improved rotations may present positive environmental impacts but insufficient economic performance compared to monoculture (see economical aspects below). This profitability gap is due to the lack of integration of external costs and benefits of the cropping systems which typically for environmental resources or services do not have a value that can be taken into cost balance calculations. Identifying the external costs and benefits (such as diminished or increased biodiversity) would therefore be an essential step towards promoting rotations with comparatively positive impacts on the environment.

Environmental benefits associated with improved crop rotations include:

- Positive impact on biodiversity, since the use of crops from different botanic families encourages biodiversity;
- A reduced need for input of chemical fertilizer (for example a reduced need for Nitrogen fertilizer if nitrogen fixing species, such as Alfalfa, are included in the rotation); and,
- A reduced release of CO2 from the soil. Furthermore, the need for fossil fuel input will decrease due to a reduced use of inorganic fertiliser.

The advantages of crop rotation were recognised in prehistoric times, following observations of the loss of soil fertility due to continuous cropping. However, the introduction of efficient and innovative crop management tools changed the picture; improved high yield crop varieties, synthetic nitrogen fertilisers, pesticides, herbicides and irrigation facilities existing today makes the use of “natural” fertilisation and soil improvement methods (such as crop rotation) less crucial to obtain good yields (BIO, 2010). In the EU today, crop rotations are in most cases short term (3 to 5 years) rotations, where a few families of plant species are used and the same nutrients are applied for most years. The exception is organic farming, where the benefits of longer crop rotations (5 to 10 years) are recognised.

Barriers for implementation of the practice exist, and may include:

- the high dependence of the practice on other agronomical factors (such as the access to organic fertiliser);
- the long term perspective; the time scale needed for SOM improvements using crop rotation as compared to monoculture, is relatively long. In many cases farmers tend to focus on next year’s profit rather than the profit over a 40 year time span;
- the economical perspective; according to Morari et al. (2006), in some regions a more intensive and widespread implementation of successful crop rotation management practices would require additional monetary incentives to become economically feasible.

The incentives and barriers for the individual farmer to introduce long term crop rotations would include the above mentioned, such as improved biodiversity and soil quality, but additional practical and economical factors will have to be taken into account. An important practical barrier is the simple fact that diverse crops involve more effort for the farmer than monoculture, in terms of machinery, labour and knowledge. Furthermore, European regions offer different types of soil and climatic conditions that limit the choices of farmers in their choice of crops to grow.
There are economical benefits associated with the improved crop rotation practice, as illustrated by the following general observations (BIO, 2010). The difference in fixed costs between cropping systems (see Table 1) depends on the characteristics of the cropping system, i.e. on the actions and equipment needed. For improved rotations, investments in machinery may be needed, generating higher costs (unless the farmer has access to a machine “pool” or similar solutions). The main variable costs are external inputs, i.e. nutrients, chemicals, energy and labour. An improved rotation practice may lower variable costs, for example by reducing the need for nutrient N if the rotation involves nitrogen fixing species. A summary comparison on data for overall profitability of different cropping systems is shown in Table 2. A crop combination to be economically (and environmentally) beneficial, it needs to be complemented by an adequate management adjustment by the farmer. In other words, to exploit the rotation effect the farmer must use less herbicide, less nitrogen, less water and less fungicide/insecticide.

Table 2 Depreciation costs (costs for fixed assets) and concentration of the cropping structure (average data) (BIO, 2010)

<table>
<thead>
<tr>
<th>Concentration of cropping structure</th>
<th>Ha/farm</th>
<th>Livestock units/farm</th>
<th>Depreciation costs (€)</th>
<th>Depreciation costs/ha (€)</th>
<th>Depreciation costs/unit of production value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>120.6</td>
<td>0.83</td>
<td>10432</td>
<td>109</td>
<td>0.184</td>
</tr>
<tr>
<td>Low</td>
<td>126.5</td>
<td>1.50</td>
<td>13728</td>
<td>86</td>
<td>0.201</td>
</tr>
<tr>
<td>All farms</td>
<td>125.0</td>
<td>1.33</td>
<td>12884</td>
<td>103</td>
<td>0.197</td>
</tr>
</tbody>
</table>

Table 3 Profitability of different cropping systems (€/ha/year) (BIO, 2010)

<table>
<thead>
<tr>
<th>Type of rotation</th>
<th>Production cost</th>
<th>Gross revenues</th>
<th>Margin</th>
<th>Sources</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous maize</td>
<td>1301</td>
<td>1634</td>
<td>313</td>
<td>L. Giardini, 40 years of experiments in Veneto Region (Italy), 2004</td>
<td>Results presented for average fertilisation schemes</td>
</tr>
<tr>
<td>2-year maize rotation</td>
<td>934</td>
<td>1701</td>
<td>767</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-year maize rotation</td>
<td>1055</td>
<td>1798</td>
<td>743</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous wheat</td>
<td>-</td>
<td>-</td>
<td>264</td>
<td>D. Forristal, Rotations: a New Role in a New Era?, 2005</td>
<td>Results of an experiment conducted in Knockberg, Ireland, high fertilization schemes</td>
</tr>
</tbody>
</table>

1 Authors’ calculations based on the Polish FADN sample (data for the year 2007). Only farms of the economic size more than 8 ESU and with the number of Livestock Units less than 10 LU/100 hectares were considered.
2 Note: the concentration of the cropping structure has been calculated for each farm using the Herfindahl-Hirschman Index (HHI). \[ \text{HHI} = \sum_{i=1}^{l} \frac{x_i^2}{100} \], where \( l \) is the number of crops in the rotation and \( x_i \) the share of crop i in the cropping structure of the farm (for example, \( x_i = 100\% \) in monoculture). The HHI has been calculated for all 496 farms of the Polish FADN sample. The farms with an HHI above (resp. under) 80% were considered as having a high (resp. low) level of concentration of their cropping structure.
Case study 1 The effect of long term crop rotations on soil organic matter status in North Eastern Italy

<table>
<thead>
<tr>
<th>Type of rotation</th>
<th>Production cost</th>
<th>Gross revenues</th>
<th>Margin</th>
<th>Sources</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal rotation</td>
<td>-</td>
<td>-</td>
<td>271</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous wheat</td>
<td>-</td>
<td>-</td>
<td>341</td>
<td></td>
<td>Results of an experiment conducted in Knockberg, Ireland, low fertilisation schemes</td>
</tr>
</tbody>
</table>

Monoculture systems are generally based on high value crops whereas crop rotations include lower output price crops. It follows that average output prices for crop rotations might be comparatively lower than for monoculture. On the other hand, an appropriate selection of crops can help minimise the expected variability in revenues. Whereas the revenues generated by crops from a monoculture are completely determined by yield and market price for one crop, in a rotation-based cropping system the farmer may modify the average output price of his production by modifying the mix, and/or the types, of crops (BIO, 2010).

Furthermore a favourable market is a key driver to take into account. For example, even though alfalfa inserted in a crop rotation has proved to enhance the levels of SOM, the decision to grow this crop (and others) largely depends on the presence of industries to transform it (BIO, 2010).

1.4 Lessons learned

The experiment shows the many factors that must be taken into account (soil type, organic fertiliser available and its quality (Farm Yard Manure/slurry), crops feasible to cultivate) when trying to predict the effect of an improved crop rotation management. Importantly, the results show that SOC declined over the first 12 years of the experiment, in all soil treatments, following the introduction of intensive soil cultivation, which emphasises the importance in choice of management method, as well as the long term perspective on soil improvement. The results of the study confirm a small rate of C increase (0.02 t C/ha/year) after changes to crop rotation and inorganic fertiliser rate with intensive tillage (Morari et al., 2006). Thus, the increase in C is marginal comparing monoculture with a more complex rotation.

1.5 Policy Trade-offs

The possible instruments to encourage diversified crop rotations may involve dissemination of results from examples such as the Padova study. At farm and regional levels, education and training can be provided by technical agricultural institutes (Farm Advisory Systems for example) including exemplification of best practices to implement on the farm. The local diverse conditions can be better taken into account with the development of farm-oriented information networks. Also, stakeholders such as industries or cooperatives/traders could work more closely with farmers (associations or individuals) and find adequate solutions that will match profits and environmental benefits of crop rotations.

At the European level policy tools exist that promote efficient management of crop rotations. Some existing EU Regulations could in a better way promote improved crop rotations as a mean to increase SOM levels, for example by defining the objectives of the practice and increasing the level of detail as to which rotation practices are
beneficial, or by providing more detailed advice and training opportunities through national or local authorities.

The Nitrates Directive and Regulations on organic products (Regulation No834/2007) can potentially have an impact on the adoption of more diversified crop rotations by farmers (BIO, 2010). In the Soil Thematic Strategy, soil organic matter is defined as the key indicator for soil quality. The strategy focuses on sustainable soil management. Long crop rotations with a high intensity management can, according to the present case study, help maintain an optimum soil organic matter status.

The 2003 Common Agricultural Policy (EEA, 2005) made the granting of community funding conditional upon compliance with environmental standards and initiatives aimed at (among others) limiting environmental pressures from agriculture and protecting biodiversity (compliance on the basis of maintaining GAECs). More developed arable crop rotation standards could be introduced into the cross compliance GAEC legislation to limit pollution from agriculture and protecting biodiversity.

On a larger scale, the role of soil organic carbon in reducing atmospheric CO₂ concentrations was recognized in Article 3.4 of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) (Lugato et al 2007). However, the effects of the management in each individual situation must be studied. Supporting Crop Rotation may not have the same effect on all soils, and may not be equally feasible in all types of farming enterprises. Therefore, policies to support crop rotations may be less feasible for some geographic regions, than others.

### 1.6 Future outlooks

The future feasibility of crop rotation management will depend on future market demands for fodder and alimentary products, reflected in trends regarding the average European’s diet, industrial uses and innovations. The market for organic product has been increasing over the past decade (Eurostat, 2010). Therefore, there is an increased need for farming practices suitable for organic production (including improved crop rotations). Also, the future demand for crops or crop residues that could be used for biofuels raise interesting questions about whether bio fuel crops can be included in, or interchanged with successful crop rotations.

Ikerd (1991) and Chou (1993) identified uncertainties about the long-term availability and the increased costs of energy use and energy-related inputs such as fertilizers, herbicides or pesticides. Total input prices have risen significantly since the beginning of the decade because of higher energy prices. This trend will almost certainly continue and is likely to be reinforced by regulation which aims at increasing the price of fossil energy by economical instruments. In this context the advantages of improved crop rotations may be increasingly recognised (BIO, 2010).

Regarding the contribution of crop rotation to processes on an EU or global scale, the management practice can be seen as a relatively small, but not irrelevant contributor in towards achieving the Kyoto Protocol targets.
1.7 References


Background Information

**Location:** France

**Biogeographical region:** The sites are located in Boigneville in the Parisian Basin in Northern France (48°33’N, 2°33’E). The fields are characterised by a climate with oceanic influence. The long term average temperature is 10.8°C and the annual precipitation is 650 mm.

**Time:** The field experiments have been carried out over 34 years, from 1970 to 2004.

**Initiator:** There were two initiators for this project: the French Agency of Environment (ADEME) and Arvalis-Institut du Végétal.

**Objectives:** Research study to evaluate the long-term effect of two tillage systems on soil organic matter.


**Key experts:** Dr B. Nicolardot (b.nicolardo@dijon.inra.fr)

2.1 Context and aims of the case study

For many centuries, the conventional mouldboard tillage system has been used in agriculture to control the development of weeds, to incorporate crop residues into the soil, to recycle leached nutrient back to the surface and to create an adequate structure before planting. Nevertheless, with the development of herbicides, the need for ploughing was questioned and reduced tillage systems began to appear. In France, the
reduction of tillage intensity by suppressing mouldboard ploughing and adopting conservation tillage techniques has become increasingly popular over the last decade.

Reduced tillage systems have two main characteristics:

- the soil is not entirely turned over; and,
- the soil is always entirely or partially covered by crop residues.

These changes are known to decrease soil erosion and increase water holding capacity. Moreover, the uptake of reduced tillage systems has induced changes in the soil structure and increased the occurrence of soil organic matter (SOM) at the soil surface. This in turn has resulted in changes in soil temperature, water content and in several other biological, chemical and physical soil properties. The combination of all these modifications has an important impact on C and N transformations in the soil.

This project was established by ADEME, the French agency of environment and by ARVALIS-Institut du Végétal, a technical institute in charge of applied research on agriculture, run and financed by farmers.

The aim of this study was to quantify the differences in C and N pools between different long term tillage systems in cereal cropping systems in Northern France. The work focused mainly on: (1) mouldboard ploughing to 20 cm depth (conventional tillage) and (2) a no-tillage system. In order to widen the perspectives of the study, minimum tillage (also known as superficial tillage) was also taken into account in the analysis.

Several parameters of the soil organic matter were assessed including: soil organic C and N and soil mineral N dynamics.

In addition, a Canadian survey (from the Prairies region) provides data on the farm economics of reduced tillage (see section 1.5).

### 2.2 The Best Practice management method

The Boigneville soil is a haplic luvisol, developed on loess, with a deep loam overlying fissured calcareous material. The calcareous material is found at 70-100 cm depth.

The soil management systems were differentiated in 1970, and the experimental plots (8 x 50 m) either received conventional tillage (CT) or no-tillage (NT). Over the last 32 years, the ploughing depth has been approximately 20 cm (mouldboard ploughing with three blades) whereas tillage was totally suppressed in NT.

Since 1970 these plots were cultivated with a maize/wheat rotation with similar restitution of residues in both management systems. This means that the same quantity of crop residues were integrated in the two systems but kept in the soil surface in the case of NT and integrated into the soil in the case of CT. The crop residues in CT were incorporated into the soil during tillage whereas those in NT always remained on the soil surface and has neither be burned nor removed from the plots.

The timings of the tillage, sowing and harvesting operations are presented in Figure 2.
2.3 Best Practice Trade-offs

- SOM stocks

The C and N stocks in soil without tillage (NT) were generally larger (Table 1), but the differences were not large. After 32 years of differentiation, the surplus C stock was 5.6 t C/ha (difference between CT and NT after 32 years). This indicates a mean annual gain of 175 kg C/ha/yr in the NT plots. Concerning the organic nitrogen, the surplus N stock was 0.39 t N/ha. This indicates a mean annual gain of 12 kg N/ha/yr in the NT plots.

Table 4 | C and N concentrations in the different soil layers of the conventional tillage (CT) and no-tillage (NT) plots at Boigneville (this profile has been done during three years but the experimentation was carried out from 32 years)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Soil layer depth cm</th>
<th>Organic C Tons C/ha</th>
<th>Organic N Tons N/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>0-27.7</td>
<td>37.9±2.7</td>
<td>4.01±0.26</td>
</tr>
<tr>
<td>NT</td>
<td>0.26.8</td>
<td>43.5±1.8</td>
<td>4.40±0.12</td>
</tr>
<tr>
<td>cm</td>
<td>g C 100/g</td>
<td>g N 100/g</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>0-20</td>
<td>1.09±0.05</td>
<td>0.111±0.004</td>
</tr>
<tr>
<td></td>
<td>20-28</td>
<td>0.73±0.07</td>
<td>0.086±0.007</td>
</tr>
<tr>
<td>NT</td>
<td>0-5</td>
<td>2.37±0.29</td>
<td>0.211±0.022</td>
</tr>
<tr>
<td></td>
<td>5-11</td>
<td>1.18±0.10</td>
<td>0.121±0.006</td>
</tr>
<tr>
<td></td>
<td>11-17</td>
<td>0.84±0.07</td>
<td>0.091±0.005</td>
</tr>
<tr>
<td></td>
<td>17-23</td>
<td>0.76±0.03</td>
<td>0.084±0.001</td>
</tr>
<tr>
<td></td>
<td>23-27</td>
<td>0.75±0.02</td>
<td>0.082±0.002</td>
</tr>
</tbody>
</table>
Case study 2 Long-term effect of reduced tillage systems on soil organic matter in Northern France

Figure 3  C and N stocks in the different soil fractions for the equivalent plough layer of the conventional tillage (CT) and the no tillage (NT) plots (bars correspond to standard errors).

Most of the difference between C and N stocks regarding the tillage practices (no-tillage or conventional tillage) was due to a larger amount of mineral associated organic matter and particulate organic matter (POM) occluded within aggregates under NT (Figure 3). In NT, lower amount of C and N were found in the free mineral-associated OM of NT than in CT: these elements are mainly present in the aggregates in NT but less so for C and N in the total free OM.

After 32 years, no-tillage system presented 5-15% larger C stocks and 3-10% larger N stocks compared to conventional tillage in the superficial layers of the soil, but these concentrations decreased with increasing depth compared to the conventional tillage where they were relatively homogenous through the plough layer. These larger C and N stocks are mainly attributed to an enhanced macro-aggregate formation in the 0-5 cm layer due to higher soil organic matter content and a better protection of this SOM in the 5-20 cm layer due to a larger proportion of small pores and lack of soil disruption by tillage or climate.

Between 1970 and 2003, with similar N fertilisation additions between CT and NT, maize plants developed more slowly in the early growing stages in NT but the final crop yields of maize and wheat were not statistically different in the two tillage systems. Since yields were not negatively affected by long-term no-tillage and organic C content was higher and since this agricultural practice consumes less energy and time compared to the conventional tillage, no-tillage appears to be a cost-saving choice for maize and wheat production under these temperate environmental conditions.
Regarding gaseous exchange N losses, ammonia volatilisation and nitrous oxide losses are generally more important in no tillage systems. Indeed, higher N$_2$O emissions were measured for NT compared to CT plots, although the differences were not significant due to a large spatial variability. Furthermore, the quantities of N lost as N$_2$O were considered negligible from an agronomical point of view.

### 2.4 Lessons learned

In no-tillage systems, compared to conventional tillage systems, the soil structure is less heterogeneous due to the absence of both incorporated residues and soil displacement and fragmentation during tillage. With respect to soil aggregates, no-tillage systems increase the amount of water stable aggregates larger than 250 µm (this means that the soil structure will not be affected by intense rainfall events) and aggregate stability is lower in conventional tillage than in no-tillage system (Tebrügge and Düring, 1999).

In terms of farm economics NT in the long term leads to a decrease in fertiliser use (according to the Canadian survey) since the soil organic matter as well as the crop residues on soil surface release large quantities of inorganic nitrogen that can be assimilated by crops. Moreover, the combination of no tillage with crop residue cover offers to the farmer a reduction in the amount of labour as well as an important decrease of the fuel consumption (explained in section 1.5). Finally, with the concern of global warming, this practice could contribute to decreasing water inputs since it conserves soil humidity better. There are two reasons for the improved water conservation: (1) no tillage practices increase the amount of soil macro pores and allows for greater water infiltration; and (2) the presence of the mulch layer reduces water evaporation.

In addition, some other benefits of no-tillage are reduced field erosion and cleaner run-off water and decreased soil evaporation due to a crop residue cover, which conserves water during drought periods (according to the Canadian survey).

According to the Canadian survey the on-farm cost of soil erosion in 1980 was estimated to be nearly $430 million in Alberta, Saskatchewan $560 million, and nearly $44 million in Manitoba. Studies on the prairies have shown that soil losses were greatest from conventional tillage and least from no-tillage management systems. Since the early 1990s, no tillage or minimum tillage along with other soil conservation practices have resulted in a significant decline in soil losses, and, as a result, only a small proportion of agricultural land is now susceptible to soil erosion (water erosion: < 14%; wind erosion 30%).

Moreover, no-tillage increases runoff infiltration by slowing the flow of rainwater or snowmelt from the field. In no-till fields, there is also more infiltration as compared to tilled fields; consequently this results in fewer pollutants entering the streams and open water bodies. Reduced runoff due to no-tillage is also associated with decreased flooding and an increase in soil moisture. However, by not tilling the soil, there is a concern that it may increase leaching of water, nutrients and pesticide to the ground water. There are conflicting reports in the literature about the role of no-tillage in enhancing leaching. Some studies have found little or no difference in leaching of water and nutrients between no-tillage and tilled fields while others report greater leaching in no-tillage soils than in tilled soils.

The success of this practice is that it shows at the same time an increase in soil organic matter content as well as a better C and N stock in the top layer of soil.
This best practice can be potentially applied in all European countries and especially in
poor soils to fight fertility losses due to erosion, leaching or run-off. Surface sealing
appears to be reduced in the no-tillage system compared to the conventional due to a
reduction of the raindrop impact by the mulch cover. Weeds respond differently to
tillage practices. Populations of some species increase under superficial and no-tillage
while others decrease.

Apart from the benefits, no tillage or reduced tillage systems may also entail several
disadvantages compared to conventional tillage. First of all, due to the need for weed
control, more herbicides are used in no tillage and reduced tillage systems. Secondly,
the surface mulch of residues may promote the presence of parasite and damaging
slugs, rats and snakes. Soil compaction associated with NT systems may cause
problems for the establishment or emergence of some crops – and increase runoff.
Finally it has to be realised that for some soils there is a real requirement for the soil to
be ploughed – meaning that NT is entirely unsuitable.

2.5 Policy Trade-offs

The aim of the author of this case study is to synthesise this database of scientific
knowledge in order to create a decision tool and then to diffuse these tools to the
farmers as well as to the French government in order to help them to analyse their own
situation. Regarding the environmental and agronomical impact of soil tillage, this has
been planned to be done in a study conducted by ARVALIS-Institut du vegetal and
funded by the French agency of environment and energy (ADEME).

The case study has not assessed the economic implications of the no-tillage system.
However, this information can be found in a Canadian survey carried out by Baig and
Gamache (2009). This survey has listed all the positive impacts of the no-tillage and
also minimum tillage systems (also called superficial tillage which appears to be a good
compromise between the no tillage and the tillage). However, the results provided by
this survey can be moderated since there is a large difference between the average
field size between Canada and EU Member States.

This survey on the cost analysis of the no or minimum tillage has shown that
conventional tillage operations took 3 times more time than no tillage (1.5 hours
compared to 0.5 hours per hectare). No-tillage reduced fuel consumption by up to
50% (see Table 2). All together, it reduced the cost of tillage, seeding and spraying
operation by 20%.

According to this survey, there is a lower cost for labour in no-tillage: 3.5 passes
compared to minimum tillage (5.8 passes) and conventional tillage (7.5 passes).
Concerning the fuel consumption, there is a significant reduction with reduced and no-
tillage as compared to conventional tillage (see Table 2)

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3 Baig M.N., Gamache P. M. (2009) The Economic, Agronomic and Environmental Impact of No-
Till on the Canadian Prairies.
Table 5  Fuel consumption

<table>
<thead>
<tr>
<th></th>
<th>Wheat on fallow</th>
<th>Wheat on stubble</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tillage</td>
<td>23.5 L/ha</td>
<td>19.9 L/ha</td>
</tr>
<tr>
<td>Minimum tillage</td>
<td>30.6 L/ha</td>
<td>24.0 L/ha</td>
</tr>
<tr>
<td>Conventional tillage</td>
<td>47.1 L/ha</td>
<td>30.2 L/ha</td>
</tr>
</tbody>
</table>

No tillage practices can enhance habitats. For example in Northern France the Common Hamster which lives in the fields is threatened by tillage practices. No tillage has also increased the population of the Little Bustard (Crex Crex): tillage practices have led to the destruction of nests and chicks, since the species nests in the open-fields during the spring.

No tillage may also reduce runoff resulting in less nitrogen loss. Several studies (Baig and Gamache, 2009; Elliot et al.⁴, 1998; van Vliet et al.⁵, 1993) have shown that no-tillage reduces sedimentation by up to up to 97% (relative to conventional tillage), and this results in a 75 to 90% reduction in total nitrogen loss for soybeans planted following corn and 50 to 73% reduction in nitrogen loss for corn following soybeans. No-tillage crop production also increases the amount of soil macro pores and allows for greater water infiltration, increasing potential for nitrate leaching.

2.6 Future outlooks

The impact of no tillage needs now to be assessed for crops other than maize and wheat (e.g. leguminous crops) in order to know if the practice does not lead to a decrease of yield.

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3.1 Context and aims of the case study

In anticipation of the implementation of the Soil Framework Directive, the report by Schjønning et al. (2009) addresses the threats to soil quality in Denmark. We have extracted and analysed the relevant information related to soil organic matter decline in Denmark.

Information is used on the effects of different management of crop residues (e.g. removal, burning and incorporation of straw) on the soil organic matter content in
typical Danish soils that have been in arable cultivation for 30 years. In addition, the relation between clay and organic carbon was studied to find a potential indicator of soil structural condition. Four experimental sites were used to assess the management of crop residues: Lungaard and Askov (55°28'N, 09°07'E), Ronhave (54°57'N, 09°47'E) and Jyndevad (54°54'N, 09°07'E) (Figure 4).

The experiments were carried out at four experimental stations in the south Jutland (Denmark). These four soils are all typical Danish soils. Their characteristics are shown in Table 6. The four soil types are mainly sandy soils but the ratio between fine and coarse sand varies. The percentage of organic matter ranges between 2.2 to 2.7% in the four soils.

Table 6  Overview of the soil types and characteristics at the four experimental stations

<table>
<thead>
<tr>
<th>Soil classification</th>
<th>Askov</th>
<th>Rønhave</th>
<th>Jyndevad</th>
<th>Lundgaard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typic Agrudalf Stagnic Albeluvisol</td>
<td>Typic Agrudalf (sandy loam soil)</td>
<td>Orthic Haplohumod (coarse sandy soil)</td>
<td>Orthic Haplohumod</td>
<td></td>
</tr>
<tr>
<td>Plough layer depth</td>
<td>21</td>
<td>25</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Clay (%)</td>
<td>12.2</td>
<td>13.6</td>
<td>4.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>13.3</td>
<td>18.5</td>
<td>2.7</td>
<td>4.3</td>
</tr>
<tr>
<td>Fine sand (%)</td>
<td>33.7</td>
<td>43.4</td>
<td>19.3</td>
<td>22.6</td>
</tr>
<tr>
<td>Coarse sand (%)</td>
<td>39.5</td>
<td>21.8</td>
<td>71.2</td>
<td>65.5</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>2.2</td>
<td>2.7</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Dry bulk density (g cm⁻³)</td>
<td>1.46</td>
<td>1.42</td>
<td>1.50</td>
<td>1.36</td>
</tr>
</tbody>
</table>

Figure 4  Location of the four experimental stations in Denmark
3.2 The Best Practice management method

In these experiments spring barley supplied with mineral fertilisers was grown every year. The annual straw production (4-5t straw/ha) was burned in the field, baled and removed, or incorporated into the soil, and the soil organic carbon levels assessed. During the last ten years of the experiment, additional experiments were carried out: the treatments were combined with a nitrate catch crop of ryegrass, split into two sub-treatments of which one was given pig slurry (35t slurry/ha annually) while the other was left without slurry. The soil organic carbon content was measured in the topsoil (0-20 cm) for a period of 29-36 years.

The experiments therefore assess the benefits of including crop residues in the soil under spring barley, and then assess the benefits of organic amendments and catch crops on soil organic carbon.

3.3 Best Practice Trade-offs

The scope for increasing the accumulation of organic matter in agricultural soils via changes in land management is linked mainly to an increase in the recycling of plant residues, an expansion of the incorporation of straw and a more frequent use of catch crops.

Figure 5 illustrates the effect of three different straw managements (removed, burned or incorporated) on three sites with different soil types: carbon was monitored from 1974 to 2003 in Askov and Jyndevad, and from 1967 to 2003 in Ronhave.

The results show that in the fields where straw was incorporated, the soil C content is significantly higher compared to the two other treatments (straw removed and straw burned), regardless of the soil type. The annual incorporation of straw has led to an increase in soil carbon storage by 13% (values presented correspond to the average of the measures for each soil and are similar regardless of the soil type).

![Figure 5: The effect of annual removal, burning and incorporation of straw on the C content in 0-20 cm soil sampled in 2002/2003 at Rønhave, Askov and Jyndevad (experiment initiated in 1974 (Askov and Jyndevad) and in 1967 (Rønhave))](image-url)
However, the experiment at the Rønhave site showed a long-continued loss of soil organic content even when straw was incorporated (Figure 6). Similar results have been obtained in farm trials under the auspices of the Danish Agricultural Advisory Service (Table 7). These results indicate that continuous spring cereal cropping with mineral fertilisers causes a long-term decline in organic matter levels even when straw is incorporated. However, the use of animal manure as well as grass crops in the rotation or adding nitrate catch crops/green manures would probably stop or moderate this decline (Dr Christensen, personal communication).

Figure 6 The effect of annual removal, burning and incorporation of straw on the C content in 0-20 cm soil at Rønhave
Case study 3 Evaluation of crop residue management options on soil organic matter levels in Jutland (Denmark)

Table 7  The effect of straw incorporation on soil C content in the plough layer in continuous spring barley cropping with mineral fertilisers - nine experimental sites with straw removed or incorporated over a period of 10 years (The Danish Agricultural Service; Skriver 1984)

<table>
<thead>
<tr>
<th>Strain incorporated</th>
<th>At experiment start 1974</th>
<th>After harvest 1983</th>
</tr>
</thead>
<tbody>
<tr>
<td>%C (0-25 cm)</td>
<td>Straw removed 1.98</td>
<td>Straw incorporated 1.77</td>
</tr>
<tr>
<td>Relative change (%)</td>
<td>100</td>
<td>89</td>
</tr>
</tbody>
</table>

Further investigations looked to see what the effect of different amounts of straw incorporation had on soil carbon content, plus the introduction of catch crops and pig slurry. Figure 7 shows results from a field experiment with continuous spring barley and mineral fertilisers in which 0 (straw removed), 4, 8 or 12 t straw/ha was incorporated every year for a period of 18 years (Thomson & Christensen, 2004). During the last 10 years of the experiment, the treatments were combined with a nitrate catch crop of ryegrass, split into two sub-treatments of which one was given pig slurry (35 t slurry/ha annually) while the other was left without slurry. Straw combined with catch crop growing gave more SOM than when straw alone was incorporated while the addition of pig slurry contributed little to OM accumulation. Compared to straw removal, the annual incorporation of 4, 8 and 12 t straw/ha over a period of 18 years caused a relative increase in the SOM level of 12, 21 and 30 %, respectively. 12 t straw/ha is not the usual practice for farmers (the average of amount of straw incorporated in a field is usually around 6 t per hectare, Baig and Gamache, 2009) but here it is used to study the effect.

![Figure 7 Soil C content (0-20 cm) after annual incorporation of 0 (straw removed), 4, 8 and 12 t straw/ha over a period of 18 years](image)

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7 The experiment was carried out at Askov with spring barley and mineral fertiliser. Treatments were straw only, straw combined with catch crop (ryegrass), and straw
An additional study looked at the utilisation of the Dexter ratio (ratio between the topsoil content of clay and organic carbon) as a tool to identify soils which have reached the critical limit in term of SOM content, and especially in organic carbon content. The method is based on the observation that there is a linear correlation between SOM and soil friability. Figure 8 maps out the Dexter index for Denmark and shows that most areas have Dexter values below the critical limit of clay/OC = 10 (yellow and the different shade of brown). Low values under 10 indicate a healthy soil depleted in complex carbon whereas values above 10 indicate threatened soils with saturated complex carbon which appear to be poor in soil organic matter. These areas generally coincide with the sandy areas across most of western Jutland. In contrast several areas with soils of morainic origin (generally the eastern part of the country) displayed in the different shade of blue indicate that the soil probably exhibits non-complexed clay. This in turn is expected to reflect tilth problems. The areas in red are close to the limit where a management strategy decreasing the SOM might turn the soil into a critical category.

combined with catch crop and pig slurry (35 t/ha/year included for the last 10 years (Thomsen and Christensen 2004).
3.4 Lessons learned

The experiments address the issue of whether to incorporate crop residues into the soil. This has implications for the use of cereals cultivated for biofuels. Conventionally all biomass produced for biofuels is removed from the soil – therefore there are no crop residues to be reincorporated. The experiments show that removal of straw from the field results in a faster decline of soil carbon content than when straw is incorporated. This means that crops grown for biofuels are detrimental to soil organic matter levels – meaning that alternative organic amendments need to be added to the soil to stop the decline.

The report also highlights the utilisation of the Dexter ratio to measure and monitor sustainable soil physical conditions in relation to soil organic matter conditions in Danish arable soils.

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8 Created from the Danish Soil Database (www.djfgeodata.dk) at Aarhus University by Mogens H. Greve.
3.5 Policy trade off

The average straw yields in this case study ranges from 3 to 5.5 t/ha. The price of one tonne of straw is around 43.5€/tonne. Thus the loss in farm income for unsold straw can range between 130 to 240 € per hectare. However, for a “mid level” rate of fertilisation ("mid level" fertilisation obtaining not the highest but at least to good yields) the average cost has been estimated by INSEE at around 130 €/ha. In the case of a strong decrease in soil fertility, this average rate can be multiplied by three, which indicates that it is preferable for farmers to incorporate straw into the soil or at least a part of the straw, in order to maintain a minimum level of fertility.

3.6 Future outlooks

The political issue of this case study was to find how land use and management should be regulated to ensure sustainable levels of SOM in Danish soils. The implications of removing all biomass for biofuels year after year have to be studied further – the experiments suggest that without suitable organic amendments this practice would accelerate the decline in soil Carbon content.

In the short term, the practice will decrease the farmer’s income, because it is incorporated into the soil and not sold. However, in the long term if the farmer continues to remove the straw from the field, the decline in soil organic matter will be so important that no more crops will be able to be grown even with the use of fertilisers.

The Dexter ratio appears to be an operational tool usable by policy makers and stakeholders to identify soils which can be used for example for the production of bio-energy crops and soils where straw cannot be removed. This tool should be combined with models in the development of decision systems and would reduce significantly the difficulties in coping with the decline in SOM in Danish agricultural soils. Moreover, the interest of this tool is that it is not compromised by soil type differences.

The use of the Dexter ratio, coupled with a combination of catch crops and straw residue for the soil with a low status of organic matter contributes to a sustainable use of the Danish soils. Moreover, the catch crops allow also a reduction of the nitrogen release and then contribute to preserve a high water quality.
Transferability and interactions with the competent authorities

According to Dr Christensen this project aims to help the Danish government for the future implementation of the Soil Framework Directive. This project appears to present a high level of transferability to most regions of the EU although of course the specific crop residues and types of manure will differ probably in a N-S transect.

The only problem underlined by this case study was that continuous spring cereal cropping with mineral fertilisers causes a long-term decline in organic matter levels even when straw is incorporated. In the researcher opinion, this decline could be limited or stopped by using animal manure rich in bedding material. However, introducing grass crops in the rotation or adding nitrate catch or green manures would probably be even better.

According to the research he believes that the Soil Framework Directive (once it will be implemented) will be very helpful to promote the practice of soil organic matter conservation as outlined in the case study.

Based on an interview with Dr Christensen
Case study 3 Evaluation of crop residue management options on soil organic matter levels in Jutland (Denmark)
# CASE STUDY 4. PRODUCTION AND MANAGEMENT OF COMPOST IN NORTHERN BELGIUM

## Background Information

| Location: | Several locations in Northern Belgium |
| Biogeographical region: | The trials have taken place in Northern Belgium |
| Time: | Trials between 1995-2006 |
| Initiator: | Several research institutes in Northern Belgium |
| Objectives: | To evaluate the effect of compost applied as fertiliser on crops (quality and quantity) and on soil quality |
| Bibliography: | Yearly trial reports and synthesis reports by VLACO (vlaco.be) |
| Key experts: | Flemish compost organisation and Soil Service of Belgium |
| | Experimental trial supervisors at Boutersem, Melle, Rumbeke, Kruishoutem, Mulishoek and Wattripont |

## 4.1 Context and aims of the case study

Agricultural soils in Belgium are confronted with a serious decline in soil organic carbon (Figure 9). During each period of three years a total of more than 60,000 soils are sampled for soil fertility advice at the Belgian Soil Service. Normal soil organic carbon contents for arable soils are 1.8-2.8% C for sand and loamy sand, 1.2-1.6% C for sandy loam and loam, and 1.6-2.6% C for (polder) clay. All soils with values below the
lower figure are considered short in organic carbon. Based on the distribution of samples into different SOC-intervals and soil types, it is estimated that arable soils have lost 25% of their SOC reserve during the past three decades.

![Figure 9](image)

**Figure 9**  
Evolution of percentage of arable soils short in soil organic carbon, based on more than 60,000 samples taken every 3 years to a depth of 23 cm (Gobin, 2005)

Compost makes a good soil amendment and an excellent source of organic matter. Compost is the product resulting from the controlled biological decomposition of organic material that has been sanitised through the generation of heat and processed to further reduce pathogens (PFRP), homogenised and stabilised to the point that it is beneficial to plant growth. VFG-compost is compost made from vegetables, fruit and garden waste. Green compost is made solely from prunings, branches, grass and leaf litter. Compost is allowed to contain a maximum of 25% industrial bio-waste but is in that case regarded by law as fertiliser or animal manure instead of VFG- or green compost. The average composition of green compost and VFG-compost indicates that compost contains valuable nutrients (Table 8). Humotex is VFG-compost obtained from aerobically composted digestion residuals.
Table 8  Nutrient content of different types of compost and release of nutrients from the VFG-compost application at 15 t/ha (VLACO, 2009)

<table>
<thead>
<tr>
<th>Component</th>
<th>Green Compost</th>
<th>Humotex VFG-compost</th>
<th>Total added from 15 VFG t/ha</th>
<th>Available after 1 year (15 VFG t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>700 kg/t</td>
<td>580 kg/t</td>
<td>590 kg/t</td>
<td>19-38 kg/ha 10-20 %</td>
</tr>
<tr>
<td>OC content</td>
<td>260 kg/t</td>
<td>210 kg/t</td>
<td>200 kg/t</td>
<td>95 kg/ha 50 %</td>
</tr>
<tr>
<td>pH</td>
<td>8.6</td>
<td>8.4</td>
<td>8.3</td>
<td>50 kg/ha 80 %</td>
</tr>
<tr>
<td>Total N</td>
<td>6.75 kg/t</td>
<td>6.00 kg/t</td>
<td>12.40 kg/t</td>
<td>188 kg/ha 19-38 kg/ha 10-20 %</td>
</tr>
<tr>
<td>Total P2O5</td>
<td>3.28 kg/t</td>
<td>5.10 kg/t</td>
<td>6.69 kg/t</td>
<td>170 kg/ha 172 kg/ha 85 kg/ha 50 %</td>
</tr>
<tr>
<td>Total K2O</td>
<td>5.70 kg/t</td>
<td>3.90 kg/t</td>
<td>9.90 kg/t</td>
<td>215 kg/ha 172 kg/ha 85 kg/ha 50 %</td>
</tr>
<tr>
<td>Total MgO</td>
<td>3.03 kg/t</td>
<td>3.60 kg/t</td>
<td>4.90 kg/t</td>
<td>74 kg/ha 85 kg/ha 50 %</td>
</tr>
<tr>
<td>Total CaO</td>
<td>16.6 kg/t</td>
<td>18.7 kg/t</td>
<td>24.40 kg/t</td>
<td>15 kg/ha 20 %</td>
</tr>
</tbody>
</table>

The beneficial effects of compost are recognised by the Flemish government. A farmer is therefore allowed to apply throughout the year a maximum of 10 t/ha VFG-compost or 15 t/ha green compost in addition to the norms set by the manure regulation under the condition that the soil is short in organic carbon content. A low carbon content is defined as <1.8%C in sand, <1.6%C in clay, and <1.2%C in loam. In addition, the nitrate residue, to be determined between 1 October and 15 November in the first layer of 90 cm of soil, has to be lower than 90 kg N/ha since the whole Flemish territory is designated as a Nitrate Vulnerable Zone according to the nitrates directive.

In 2009 a total of 1,135,000 t of bio-waste consisting of different sources of biomass was processed into different plants. What is remarkable is the growing share of industrial bio-waste (e.g. food industries) in biomass processing since 2006 (Figure 10). VFG-compost is abundantly available in the densely populated region of Flanders where it originates from kitchen refuse and garden waste. The total production of 355,000 t, however, is not sufficient to meet the demand. The supply of arable soils low in organic carbon with 10 t/ha would require 600.00 t. If Flanders were to replace 20% of peat imported, or 300.000 m³ peat, then an additional 200.000 t VFG-compost would be required (VLACO, 2009).

Based on their own marketing records, the Flemish compost organisation estimates that the majority of total compost production in Flanders (62%) is used for the maintenance of public green spaces, followed by 20% which is used in agriculture (Figure 11) (VLACO, 2009). Other applications include landfill cover or soil remediation. In the case of public green and potting soil, compost is used as an alternative to peat. An estimated 115.000 kg CO₂ emissions due to peat extraction and transportation would be saved if one fifth of peat would be replaced by compost.
Figure 10  Processing of bio-waste under VLACO certification with projections for 2010 (VLACO, 2009)

Several long-term compost trials have been conducted in Belgium, the results of which are discussed in the next section. They include arable crop rotations at Boutersem, fodder crops and maize at Melle (2), vegetables at Rumbleke (2), vegetables at Muilshoek (2), vegetables and organic farming at Kruishoutem (2) and arable crop rotations at Wattripont (1). The aim of these compost trials is to quantify the effects of composts, applied as a fertiliser, on crops (vegetable and arable) and on soil quality in terms of chemical, physical and biological soil properties. Results were compared with those obtained under conventional mineral fertilisation plots. For high application rates a derogation on the application standards was obtained.
4.2 Effects of compost on soil characteristics

Increase in carbon content

On a loamy soil with an initial carbon content of 1% in 1996, a yearly application of 15 t VFG-compost/ha resulted in 1.4% SOC content after 12 years; a yearly application of 45 t resulted in 2% SOC and a 3-yearly application of 45 t in 1.1% SOC (Bries et al., 2008; Figure 12 upper left). On a sandy loam with an initial carbon content of 1.55%, a yearly 22.5 t compost/ha resulted in an addition of 0.2% SOC after 10 years (Cognon and Reheul, 2008; Figure 12 – upper right). A 12 year trial on a light sandy loam with an initial carbon content of 0.75% and a yearly dosage of 40 t VFG-compost/ha in addition to pig manure resulted in an additional 0.1 % SOC (Sleutel et al., 2008).

Results from all experiments demonstrated that an additional 0.15 to 0.33% SOC content can be expected after 10 years of compost application at a rate of 10-15 t/ha. Only yearly compost applications result in a significant higher carbon content and a significant increase can only be realised in soils with low initial carbon contents.

![Figure 12](image)

**Figure 12** Evolution of carbon percentage in long-term field trials (1997-2008) with different compost applications under arable crop rotation on loam (upper left), under maize (upper right), under arable crop rotation loamy sand (lower left) and vegetables (lower right)

Soil chemical properties

Based on several years of experimentation, compost is found to add valuable nutrients to the soil (Table 8). The evolution of total nitrogen (NO₃ and NH₄) on cropped parcels shows an increase until March due to mineralisation followed by a decrease until harvest reflecting crop uptake (Figure 13); mineralisation starts after harvest with renewed uptake at the onset of vegetative growth of the catch crop. N dynamics on the different fallow parcels reflect the combined effect of mineralisation and leaching (Figure 13). Flemish farmers, however, are not always in favour of compost application to their fields for risk of introducing potentially toxic substances to their soils or non-compliance with the Nitrates Directive. Therefore Nitrate residues to a depth of 90 cm
have been carefully documented between 1 October and 15 November in all compost trials (Figure 14). Compost applications result in enhanced mineralisation and a potential exceedance of the nitrate norm the year after in cases of early harvests (e.g. 2004). The practice of catch crops at the end of the main cropping season not only results in lower nitrate concentrations but also in higher carbon contents (Figure 14, bottom).

Figure 13  Evolution of total N (NO₃ and NH₄ in kg/ha) in 0-90 cm soil layers during the growing season of winter wheat (sown 17/11/04; harvested on 18/8/05) followed by mustard (sown 12/09/05) on a loam soil (Gobin et al., 2005). Compost applications (y and 2y objects) on 16/11/04 (Gobin et al., 2005)
Figure 14  Nitrate residue under arable crop rotation for different compost applications on sandy loam (top: 40 t/ha) and loam (bottom). The red line indicates the allowed maximum of 90 kg NO$_3$-N/ha for the first 90 cm.

**Soil physical properties**

Soil physical properties improve due to compost application. On a loam soil, a 9 year application of 15 t VFG-compost/ha/yr resulted in a 1 volume % increase in total available water content and 45 t VFG-compost/ha/yr resulted in a 4 volume % increase in total available water content (Figure 15, upper left). After 5 years of compost applications, infiltration rates increase and run-off rates decrease even under relatively small application rates (Figure 15, upper right). The increased infiltration rates, however, do not necessarily add to more nitrogen leaching since the latter depends largely on mineralisation. Yearly compost application rates on a loam soil doubled the aggregate stability, making the soil less prone to soil erosion. After 7 years of compost applications on a light sandy loam, total pores significantly increased and the bulk density decreased by up to 13% (Figure 15, lower left). Effects of compost application on the soil moisture retention curve show significant effects on gravitational water (between pF0 and pF1).
Case study 4 Production and management of compost in Northern Belgium

Figure 15 Soil moisture content (in vol.%, upper left) and infiltration rate (in mm/h, upper right) on loam, total pore space and bulk density (lower left) and the soil water retention curve (lower right) on loamy sand under different compost applications

Results from a laboratory rainfall simulator experiment with compost used as a mulch demonstrated that runoff decreased with increased compost application. Three types of compost (green compost of 0 - 20 mm size, green compost of 0 – 40 mm size and VFG-compost) were applied at four different application rates (25, 50, 75 and 100 t/ha) to a loam soil. An application of 25 t green compost/ha resulted in 20 to 25% less wash erosion (Figure 16, left) and 50% less splash erosion (Figure 16, right).

Figure 16 Wash (left) and splash erosion (right) under different compost applications as related to cumulative rainfall measured during rainfall simulations
Soil biology

Earthworms strongly increase microbial activity and mineralisation. Earthworm counts at different experimental sites have demonstrated a doubling in anecic and epigeic worms (deep and lateral burrowers), whereas endogeic worm counts (shallow burrowers) are not always significantly different between mineral fertiliser and compost treatments (Figure 17, right; Gobin et al., 2005). A synergism between stable manure and VFG-compost was observed in relation to earthworm population (Figure 17, left; Cougnon et al., 2008).

Yields

Different trials comparing the crops under no fertiliser, mineral fertiliser and different compost applications rates (15, 30, 45 t/ha/year) indicate that compost at higher and yearly application rates does as well as or better than mineral fertiliser on its own for most of the years (Figure 18). Compost application rates, however, were topped with mineral fertiliser taking into account nutrient release (Table 8) in order to compare soil fertility effects. The effect of VFG-compost application on 9 years of maize yields (Bommelé and Reheul, 2005) shows the difference between application rates (Figure 19, left). For five of the nine years the yield increase is under 20%, whereas for two years the increase in yield is over 60% at 22.5 t/y. Yearly applications result in higher yield increases during the later years, whereas bi-annual higher application rates provide for better results during the initial years. The comparison over 9 years of average arable yields when VFG compost is applied and when there is no fertilisation (Figure 19, right), is also variable – the potato yield increase is less than 10%, whereas maize and sugar beet are 26% and 24%, respectively.
Lessons learned

The following lessons can be drawn from the experimental results:

- **Yield:** both quantity & quality of agricultural products increase as tested on several vegetable and arable crops. Potato yields increased by 3.5-10%; lettuce by 25%; carrots by 5-8%.
- **Plant health:** Compost is free from weed seeds and disease organisms. Depending on the crop and disease, pesticides may be reduced by 20% or avoided according to several trials.
- **Soil chemistry:** Compost offers a well-balanced slow release supply of nutrients. The carbon content in soils doubles after 10 years at higher application rates and increases with 50% at lower rates.
- **Soil biology:** More earthworms occur as indicator for increased soil biological life.
• Soil physics: compost retains 80 to 115 litres of water per t. Compared to the application of mineral fertilisers, the soil water retention improved by 10-40 l water per m³ soil, the infiltration rates increased 5 to 10 times, the aggregate stability doubled, surface sealing decreased by up to 60% and soil loss due to erosion was found to be 20-30% lower or 1 – 1.2 t/ha lower.
• Application rates: Yearly applications of small doses (e.g. 15 t/ha/a) have a superior effect on C-sequestration as compared to an accumulated application every 3 years (e.g. 45 t/ha/3a).
• Climate: The use of compost avoids emissions in comparison with peat use (167 kg CO₂/t) and fertiliser use; carbon is added to the soil with a C-sequestration potential of 8% (54 kg CO₂/t compost).
• Environment: Soil regulatory and supporting functions improve, but care needs to be taken of the nitrogen content, trace elements and other components present in compost.

4.4 Future outlooks

Policy and economic aspects

• According to 2007 data, Flanders saves 334 kt CO₂ through composting green waste and 210 kt CO₂ through composting household refuse instead of burning bio-waste. This corresponds to the yearly emissions of 240,000 cars at 15,000 km/year or the yearly electricity use of 200,000 families at 3,500 kWh/year.
• Digestion of biomass followed by composting offers possibilities of both energy production and recycling bio-waste in the form of soil amendments.

Environmental applications

• The environmental benefits in terms of avoided soil loss, increased nutrient and carbon supply, avoided pesticide use and increased water retention was calculated at 55 €/t green compost and 65 €/t household refuse compost.
• The constraints of using household refuse compost on farmland, as perceived by farmers, are related to the addition of trace elements (particularly heavy metals) or potentially other substances (pesticide residues) to farmland.

4.5 References


CASE STUDY 5. PRODUCTION AND MANAGEMENT OF SUGAR-BEET COMPOSTS (VINASSE) IN SOUTH WESTERN SPAIN

Background Information

Location: South Western Spain

Biogeographical region: The sites are located in the Guadalquivir river valley, SW Spain, at the experimental farm La Hampa in Coria del Rio, Seville. The region is under a Mediterranean climate.

Time: Trials between 1995-2006

Initiator: The field experiments have been carried out from March 1993 to July 1995.

Objectives: Research study to evaluate the effect of three vinasse composts applied as a deep fertiliser on crops and the effect on some chemical properties of the soil.


Key experts: Engracia Madejón `emadejon@irnase.csic.es), from the department of Protection of Soil-Water-Plant-System at the Institute for Natural Resources and Agrobiology of Seville (IRNAS). This expert is mostly involved in the development of systems for soil evaluation and monitoring oriented to the soil protection, the crop protection as well as the agricultural management.
5.1 Context and aims of the case study

South-western Spain is characterized by very erodible soils, developed over soft rocks and under an aggressive climate (Figure 20). But, probably the most important factor is the human activity, which has triggered soil and vegetation degradation processes: agriculture has led to the reduction of vegetation cover, and an increase in overland flow and soil loss mainly due to an increase of the erosion process. The use of organic fertilisers has a positive effect on soil fertility (improvement of physical, chemical and biochemical soil properties).

The aim of this study was to quantify the effects of three vinasse (vinasse is a dark brown effluent with high organic matter content generated during distillation of alcohol) composts from sugar-beet, applied as a deep fertilizer (which means at 10-15 cm depth), on crops (corn and sugar beet) and on some chemical properties of a cambisol soil (soil with a beginning of soil formation and a weak horizon differentiation) with a focus on soil organic matter, over two successive compost applications. Residual effect of the compost on a third crop (sunflower) was also evaluated. Results were compared with those obtained under traditional mineral fertilisation and without application of any fertilisation to the soil. The assessment of the use of compost from vinasse residues is new, but the results need to be taken with caution when extrapolating to other areas as the experiments are done over a period of only 2 years.

![Map of Annual erosion risk in Spain](source: www.kwaad.net/SoilConservation.html)

**Figure 20** Annual erosion risk in Spain

5.2 The Best Practice management method

As the decrease in soil fertility through soil erosion is one of the major reasons of yield decrease in South Spain, the goal of this case study was to find a suitable practice to improve crop growth.

The composts were used in field experiments to study the effect of their application on crops and on the chemical properties of a calcareous loamy sand soil classified as

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9 According to the FAO World Reference Base for Soil Resources, a cambisol is a soil with a beginning of soil formation, characterized by the absence of a layer of accumulated clay, humus, soluble salts or iron and aluminum oxides.
Case study 5 Production and management of sugar-beet composts (vinasse) in South Western Spain

Cambisol (FAO, 1988) or Xerochrept (Soil Survey Staff, 1996). The initial composition of the three different composts was:

- Compost G: 82% grape-marc and 18% vinasse
- Compost O: 76% olive pressed cake, 17% vinasse and 6% leonardite
- Compost C: 47% cotton gin trash, 49% vinasse and 3% leonardite.

At all, five treatments were carried out: application of each of the three vinasse composts, application of an inorganic fertiliser and a control treatment (without any fertilisation).

The following treatments were established for 2 years in plots of 5x7.5 m and four replicates per treatment were randomly established in a complete block design. The experiment was performed following the conventional crop rotation practice in the area: corn, sugar-beet and sunflower. In the first period (March-October 1993), corn (Zea mays L. 'Dakar') was cropped (7.1 plants/m²) under irrigation (439 mm). In the second period (November 1993–June 1994), sugar-beet (Beta vulgaris L. ‘Taurus’) was cropped (10.6 plants/m²) under reduced irrigation (167 mm). In the third year sunflower (Helianthus annuus L. ‘Florasol’) was cropped (7 plants/m²) without fertilisation (residual effect) and under very reduced irrigation (71 mm). Sunflower was chosen to evaluate residual effect because it is a plant that currently used in the area as scavenger crop whereas the two first crops received variable amount of composts and inorganic fertilizer. In the first period, the three composts and the inorganic fertiliser were applied 40 and 60 days after sowing and in the second period the fertilisers were applied 35 and 70 days after sowing. Table 9 presents the different technique itinerary carried out during this study.

Table 9  Presentation of the four fertilisation treatment

<table>
<thead>
<tr>
<th></th>
<th>Compost G</th>
<th>Compost O</th>
<th>Compost C</th>
<th>Inorganic fertiliser:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics of</strong></td>
<td>500 g/kg OM²</td>
<td>708 g/kg OM NO₃-N: 323 mg/kg</td>
<td>501 g/kg OM NO₃-N: 678 mg/kg</td>
<td></td>
</tr>
<tr>
<td><strong>the composts</strong></td>
<td>NO₃-N: 92 mg/kg</td>
<td>NO₃-N: 82 mg/kg</td>
<td>NO₃-N: 678 mg/kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C₇₀影视⁴: 26.4 g/kg</td>
<td>C₇₀影视⁴: 27.0 g/kg</td>
<td>C₇₀影视⁴: 16.9 g/kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C₇₀影视⁶: 20.0 g/kg</td>
<td>C₇₀影视⁶: 17.9 g/kg</td>
<td>C₇₀影视⁶: 43.9.4 g/kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C/N: 12</td>
<td>C/N: 35</td>
<td>C/N: 9.6</td>
<td></td>
</tr>
<tr>
<td><strong>First</strong></td>
<td>15000 kg/ha</td>
<td>35000 kg/ha</td>
<td>7500 kg/ha</td>
<td>1000 kg/ha</td>
</tr>
<tr>
<td><strong>rotation: maize</strong></td>
<td>crops</td>
<td>crops</td>
<td>crops</td>
<td>crops</td>
</tr>
<tr>
<td></td>
<td>Two top-dressings each of 300 kg ha⁻¹ of urea (460 g kg⁻¹ of N) applied 40 and 60 days after sowing.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Second</strong></td>
<td>14000 kg/ha</td>
<td>22000 kg/ha</td>
<td>15000 kg/ha</td>
<td>6000 kg/ha</td>
</tr>
<tr>
<td><strong>rotation: sugar-beet</strong></td>
<td>crops</td>
<td>crops</td>
<td>crops</td>
<td>crops</td>
</tr>
<tr>
<td></td>
<td>158 kg/ha superphosphate (350g/Kg P₂O₅)</td>
<td>122 kg/ha superphosphate (350g/Kg P₂O₅)</td>
<td>6000 kg/ha complex fertilizer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Two top-dressings each of 90 kg/ha of urea (460 g/kg N) applied 35 and 70 days after sowing.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sunflower</strong></td>
<td>No fertilisation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

²OM = Organic matter
⁴CHA = humic acid-C
⁶CFA = fulvic acid-C
5.3 Best Practice Trade-offs

This case study highlighted the positive effect of three vinasse composts on soil organic matter content. One of the clearest effects of compost application was the increase in the soil organic matter content. After each crop, mean values of total oxidizable C (Cox) in soils treated with the three composts were higher than in soils from the other treatments, the differences being statistically significant in most cases (Figure 21). The same trend was observed for the mean values of C in the humic extract (CHE).

Concerning the agronomic effects of these three vinasse composts, they increased significantly sunflower yield compared to the inorganic fertiliser application (from 33% for the compost G to 100% for the compost O). For corn the yield increase was better with compost C which is improved by 25% compared to the treatment with the inorganic fertiliser and for sugar beet, compost G produces the best yield increase (20% more compared to IF treatment). All the results concerning the treatment effects on yield crop are summarised in the Figure 22. The composts G and O appear to be the most relevant since their use never provide a decrease in term of yield compared to the conventional fertiliser used by the farmers (IF). This means that with the compost G and C, farmers can preserve the soil organic matter content of their field and the yield expected by farmers with the use of a more conventional inorganic fertiliser.
Figure 22 Effect of treatment on yield of corn (a), sugar-beet (b) and sunflower (c). In each plot, values with the same letter do not differ significantly (p<0.05).

(G = compost G with grape-marc and vinasse; O = compost O with olive pressed cake, vinasse and leonardite; C= compost C with cotton gin trash, vinasse and leonardite and FI= inorganic fertilizer)

Table 10 Soil mean values (0-30 cm) of Kjeldahl-N, NO3-N and available-P (Olsen) after each crop

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Kjeldahl-N (mg/kg)</th>
<th>NO3-N (mg/kg)</th>
<th>Available P (mg/kg)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>After the first crop (corn)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>719 a</td>
<td>9.6 a</td>
<td>12.5 a</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>1043 bc</td>
<td>11.7 a</td>
<td>15.8 a</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>1100 c</td>
<td>6.9 a</td>
<td>13.4 a</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>832 ab</td>
<td>13.3 a</td>
<td>13.1 a</td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>730 a</td>
<td>13.8 a</td>
<td>14.3 a</td>
<td></td>
</tr>
<tr>
<td>After the second crop (sugar beet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>648 a</td>
<td>8.0 a</td>
<td>12.1 a</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>1008 b</td>
<td>13.9 a</td>
<td>13.6 a</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>1492 b</td>
<td>12.3 a</td>
<td>13.4 a</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>889 ab</td>
<td>15.5 a</td>
<td>12.3 a</td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>748 a</td>
<td>10.6 a</td>
<td>19.4 a</td>
<td></td>
</tr>
<tr>
<td>After the residual crop (sunflower)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>798 a</td>
<td>7.3 a</td>
<td>13.7 a</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>1042 ab</td>
<td>9.6 b</td>
<td>15.4 a</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>1092 b</td>
<td>13.2 c</td>
<td>16.7 a</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1008 ab</td>
<td>9.2 ab</td>
<td>15.9 a</td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>833 a</td>
<td>7.8 ab</td>
<td>20.8 b</td>
<td></td>
</tr>
</tbody>
</table>

*Values followed by the same letter in the same column and for the same period do not differ significantly (p<0.05).*
Despite the salinity and Na content of the composts, no sigh of salinisation or sodification of the soils was observed after two years of experiments. However it is recommended to continue to monitor the soil of these fields to be sure that no problem would appear after a decade or more. This case study has introduced a new approach since it served two objectives: a restoration of the soil fertility through an increase in organic matter content and a recycling of agricultural waste components.

The success of this practice is that it shows at the same time an increase in soil organic matter content and no decrease in the crop yield compared to the data obtained with the inorganic fertilisation application. The use of these composts can contribute to enhancing the level of organic matter in agricultural soils in SW Andalusia, which are particularly poor in organic matter. At the same time, the application of compost as a deep fertiliser had similar effects on nutritional status and yield of corn and sugar-beet to those caused by a complex inorganic fertiliser.

This best practice can be potentially applied in all the European country but specially in the Mediterranean area since it is in this region that the problem of soil fertility loss due to erosion processes are the highest.

Moreover the application of safe compost with a high nutrient content could be one of the most economical and suitable approaches for increasing yield of certain crops as well as for preservation of soil fertility. This approach presents also two main environmental applications for this best practice. First it allows a restoration of soil fertility without the use of chemical fertilizers and it enhances a suitable recycling of all the agriculture waste products at the same time.

5.4 Policy Trade-offs

Compost applications of vinasse can improve erosive prone soils and is an example waste recycling without environmental harm.

The spreading of compost can be accomplished very effectively with rear discharge muck spreading equipment. A spreader can hold 10 tonnes that takes 3 minutes to load and another 3 minutes to spread. Turnaround time depends on the distance from the loading area to the field but can be as short as 10 minutes. However, a typical daily rate of application would be 200 t/day (regardless the area size). With labour, the cost of a loader and the tractor plus spreader hire charges, the application cost per tonne of compost works out at 1.85€/t, or 55.50€/ha based on 30 t/ha applied. This cost is compensated by the reduced costs of applying artificial fertilisers.

Haulage costs are the principal limiting factor on assigning a delivered and spread cost to compost. Depending of the region and the nature of the compost, the price can vary between 0€/t to 30€/t (based on information provided by farmers’ forum10). Due to the low bulk density of compost generally a lorry load will be equivalent to 16 tonnes. The haulage distance will limit whether the farmer is able to collect and spread compost or whether contractors would need to be employed. Using farm haulage equipment may be cheaper due to fuel price differentials and because existing equipment can be used during quiet times.

Contracting costs need to be assigned according to an individual site. For guidance at an application rate of up to 35t/ha a spreading cost of 3.50€/t and haulage of 6.25€/t giving an overall cost of 9.75€/t (excluding VAT) might be quoted.

According to several researches, lower costs of delivery and spreading have been quoted but again this is dependent on proximity of the source of compost to the land to which it will be applied.

Overall, the value of applying good quality compost to farmland is in the long term improvement of soil and land as an asset. The value of the compost as a fertilizer, its liming qualities and for soil improvement effects giving water savings through reduced irrigations are partially offset by the cost of haulage (120€/ha) and spreading (55.50€/ha). Depending on the crops being grown, soil type and the circumstances around a given farm, this gives a net value of compost, applied at 30 t/ha, of 2.55€/t assuming farm equipment is used for haulage and spreading rather than contractors. Further value may be ascribed to compost from yield improvements according to the crop being grown.

5.5 Future outlooks

This case study appears to be particularly interesting for all the south of Spain since all the region suffers of soil erosion as well as soil fertility decrease. Then this study could be useful for the policymakers and the stakeholders since it promotes a sustainable practice. At a larger scale, this study could impact the agronomic policy of all the Mediterranean country since the same problems are encountered.

Besides the positive impact of this practice on the soil organic matter, this study has also pinpointed the positive effect on several crops. Then, this practice should be extended at all the culture systems. This practice offers an opportunity for the farmer to obtain a fertiliser with a high organic matter content. Thanks to the process of co-composting, this vinasse compost appears to not contain high salinity levels. However, this practice is only available at a small scale since to use this vinasse compost, farmers need to live close to a sugar industry. But in this case, the cost are highly reduced compared to the use of inorganic fertiliser since vinasse is considered as a waste and farmers have just to pay for the transportation to the farm where it will be stored.
Transferability and interactions with the competent authorities

Dr Madejon and his team have several collaborations with the regional Government of Andalusia on this topic. Moreover, the compost application has been performed on farmer fields of the region, adapting to the real conditions. In this manner the transference of the technology has been the first aim. This effort was summarised in the LIFE-COMPOST Project, a demonstration project to disseminate guidelines detailing the optimal conditions for compost production in Andalusia and the application of these composts in the South-Spain and Portugal. In addition the researcher and his team have contributed to extending the use of compost in degraded and contaminated areas such as the “Green Corridor of the Guadiamar”, in which they have been monitoring and studying the effects of organic amendments on soil and plant quality for more than 10 years.

Despite the clear and positive effects of composts of high quality, the farmers are still suspicious about the benefits. In his opinion there is a need to organize more workshops/seminars for farmers and technicians to improve the dissemination of the farm trial results and demonstrate further the benefits of this farm management practice.

Based on an interview with Dr Madejon

5.6 References


CASE STUDY 6. EFFECTS OF AFFORESTATION ON ARABLE LAND IN NORTHERN EUROPE

Background information

Location: The Case Study is based on a study of three sites situated in north-western Europe (Sweden, Halland; Denmark, Vestskaven and Gejlvang, and; the Netherlands, Selligen. In addition EU-wide data from other publications have been used.

Biogeographical region: The trials have taken place in a mainly oceanic, maritime climate.

Time: Sampling between 1999-2003, chronosequences ranging from 1 to 90 years.

Initiator: Swedish University of Agricultural Sciences (SLU), Department of Forest Soils.

Objectives: To increase knowledge of several environmental aspects of farmland afforestation.


Key expert: Dr Lars Rosenqvist
E-mail: larsrosenqvist@gmail.com

6.1 Context and aims of the case study

This case study focuses on the effects of afforestation on former arable land on carbon storage and, more specifically, the effects on soil organic matter (SOM) status. A land-
use change from cropland to forestry may provide benefits to SOM; the decomposition rate of organic matter is expected to decrease as a result of changed temperature and moisture conditions, the introduction of specific litter types, and the cessation of frequent soil cultivation (Vesterdal et al. 2002).

As a background, forests today cover 37.8% of the EU's land area (166 million hectares). The forest area in the EU has been increasing slightly (0.07 - 0.09 %/year) from 1990 to 2005 (FAO, 2005). Parts of this increase took place through afforestation. In total, out of about 1 million ha of newly forested land created in Europe during the 1990s, a quarter could be associated with the withdrawal of farming (Figure 23). In particular afforestation has taken place in Ireland, Portugal, Spain and the UK, Scotland (EEA, 2005).

A survey realised in 2006 in eight countries (Austria, Denmark, Germany, Greece, Hungary, Ireland, the Netherlands and Spain) showed that 25% of non-occupational farmers have plans for afforestation. The interest in future farmland afforestation is lowest among full-time farmers (14%) (Præstholm, 2006).

![Figure 23: Contributions to Total European forest and woodland creation (%)](image)

**Source:** European Environment Agency, *The European environment — State and outlook, Copenhagen, 2005*

The case study is based on publications of data from sites located in North-Western Europe, mainly Vesterdal et al. (2007). In this publication, the data collected was compared with data from previous studies of afforestation of arable land. The changes in C buildup and storage following afforestation were evaluated in mineral soil, forest floor and tree biomass (above and below ground).

The sites investigated included two oak (*Quercus Robur*) and four Norway spruce (*Picea Abies*) stands in chronosequences aged 1 to 90 years. Their location in Sweden, Denmark and the Netherlands are indicated in Figure 24. A chronosequence in this case is defined as a series of parallel arable and afforested sites where the individual plots in the series differ in time since land use conversion. All sites within a chronosequence are located on similar soils, experiencing the same climate and deposition regime. Thus, for each sampled afforested site, a sample was also taken from an adjacent soil under agricultural cultivation.

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11 Forest floor is here defined as the layer of dead organic matter which covers the mineral soil, including e.g. leaves, branches and needles.
Soil types vary from sandy, nutrient poor soil to clay-rich and nutrient-rich soil. Data was collected through sampling of each chronosequence stand (different plots thus represent different points in time following afforestation of arable land). Above and belowground biomass C storage was monitored, and forest floor and mineral soil were sampled for soil C storage.

The conclusions drawn in this case study are mainly based on the publications on the data collected from North Western Europe, and the conclusions are therefore mainly applicable for this region. To give a European perspective in the case study, in a general discussion (where indicated) additional information has been collected from other scientific publications and other geographic regions within the EU.

### 6.2 The Best Practice management method

Afforestation implies the creation of forest, either where forest has not existed before, or where the land has been deforested a long time ago (for example to be used for agriculture). The best practice in this case would indicate the practices which maximize the carbon sequestration in the forest ecosystem including the soil, while minimizing adverse economical, social and environmental effects. The publication by Vesterdal et al. (2007) a certain type of afforestation scheme or forest management being more fruitful than others on the EU level with regard to carbon accumulation. However, some conclusions were drawn about the importance of soil types and tree species for afforestation effects.

### 6.3 Best Practice Trade-offs

**Results of the field trial**

Vesterdal et al. (2007) report an increase in biomass- and forest floor C levels following afforestation of agricultural land. Depending on the type of soil and its nutrient status, mineral soil C levels may also increase.

For the total forest compartment including tree biomass, forest floor and mineral soil, C sequestration was evident at all the sites. Out of the total C increase for the chronosequences, two thirds were observed to be accumulated in the tree biomass. Between 0 and 31% of total C was accumulated in the soil compartment (forest floor and mineral soil plough layer). With an annual average sequestration of 0.8 Mg/ha/yr, the C sequestration in the soil compartment ranged from minus 0.24 (Vestskoven, DK) to plus 1.26 (Oak/spruce, NL) Mg/ha/yr, see Figure 25.

The variability in mineral soil C can partly be attributed to differences in mineral soil properties (e.g. soil texture and clay content) and cropland management history among sites. The most notably positive change in soil C took place on nutrient poor sandy soils
(sites Norway spruce, Gejlvang and oak and spruce, the Netherlands, C increase 0.66 and 1.14 Mg/ha/yr), whereas a decline could be noticed for the nutrient rich soil at Vestskoven (minus 0.48 Mg/ha/yr). The Swedish spruce chronosequence finally, on fertile soil, showed nearly unchanged mineral soil C stocks over 90 years.

Afforestation, according to the present case study, induces a qualitative change in SOM, as revealed by an increasing C:N ratio over time. This means the composition of the organic matter in the soil changes to contain less nitrogen in more carbon. The explanation may be that the nitrogen-rich organic matter present in the previous agricultural soil is becoming gradually depleted, and the plant residues from the forest are comparatively carbon-rich. This also means that organic matter is reorganized from the previous plough layer to the top soil and forest floor (Rosenqvist, 2007).

**General discussion**

Afforestation requires important investments which are generally not justified taking only agro-economical objectives into account (DFLRI, 2001), but may be justified if in addition the expected environmental advantages are considered (as previously discussed). Afforestation may take place through state forest districts or by grant aided private initiatives. Reasons for afforestation may include an increase in demand and price for timber, or a need to find an alternative use of agricultural land. Afforestation may also be a land use strategy to reduce agricultural overproduction (Selby & Petajisto, 1995); Reasons for afforestation also involve advantages associated with forests or forest production, including:

- Increased recreational or biodiversity value;
- Increased awareness of biodiversity issues (Madsen 2002);
- Social benefits including employment opportunities or maintenance, since afforestation of farmland may be an alternative source of income in regions where agriculture faces difficulties (AAE, 2005);
- Improved water quality protection (protection of groundwater reserves, reduced nitrate pollution of water bodies) and improved water retention. However, the effects of afforestation on water quality through leaching of nitrate from forest following afforestation depend on forest management such
as fertilizing practice (Rosenqvist, 2007). The present study suggests that afforestation decreases nitrate leaching with more than 75% compared with the arable land use it replaces, although the ability of new forests to retain N varies (Hansen et al. 2007);

- Improved stabilisation and protection of soils in erosion prone or sand drift areas;
- reduction of atmospheric carbon dioxide (CO2) by increasing the stock of carbon (C) in the growing forest; and,
- improved local climate (shadow, shelter).

Importantley, forest management has a great impact on the outcome in terms of advantages and disadvantages of afforestation. There have been debates of the disadvantages of intensive forestry practices for example for biodiversity and recreation (Larsson et al, 2009).

Source: Rosenqvist, 2007

Figure 25 Total soil C changes due to afforestation (former plough layer + forest floor).

There are a number of negative aspects or barriers which need to be taken into account and counteracted when considering afforestation, which include:

- negative environmental impact of certain forest management practices (such as: an unnecessary disturbance of biodiversity caused by poor harvesting techniques, or; when afforestation takes place on land with high conservation value, such as some wetlands) (EEA, 2005);
- reduced water recharge to groundwater and runoff to surface waters depending on the selected species for the afforestation (Farley et al. 2005);
- cultural aspects such as the change in the existing landscape, which may be perceived as negative. However, this would depend on the magnitude of afforestation (Larsson et al 2009). Furthermore, in parts of Scandinavia
where large parts of the land is already under forest field afforestation can be seen as a threat to the countryside, since it symbolizes the closing down of agricultural land and a loss of rural vitality (Selby & Petajisto, 1995);

- soil acidification (depending on the selected species). Ritter et al. (2003) found that soil acidification was the most apparent change in soils following afforestation, with a soil pH decrease from 6 to 4 in the upper 5 cm of the soil; and,

- higher solubility of heavy metals (Andersen et al., 2002), for example Zn and Cd solution concentrations are known to increase in ground waters as a result of the high metal solubility at low pH (below pH 5.5).

For the individual farmer, and in a European perspective, the advantages of forestry compared to agriculture may involve the above factors. The economic advantages or disadvantages have varied with time, and depend mainly on market price for crops (including forest), subsidies or other policy support given to agriculture (or afforestation). Private farmer costs for the afforestation of agricultural land were not available within the project in focus of the case study. Therefore, to give an overall idea of the private farmer costs and benefits associated with afforestation projects, data from different European examples available in scientific publications have been included here. Costs and benefits in individual MS will finally vary depending on a number of factors.

Tassone et al. (2004) studied private farmer costs and benefits for afforestation of agricultural land in the south of Italy (Table 11 and Table 12). Afforestation costs include site preparation, purchasing, transportation and installation of the bedding plants, fertilization, fencing and wheel track set up. Maintenance costs include purchasing, transportation and installation of new bedding plants to replace dead plants, cultivation care, irrigation, and form pruning. Afforestation and maintenance costs differ according to the type of plantation considered. Maintenance costs are considered relevant only for the first 5 years.
Table 11  Costs$^{12}$ for private farmers for afforestation in southern Italy (Tassone et al. 2004)

<table>
<thead>
<tr>
<th>Type of plantation</th>
<th>Afforestation costs (€/ha)</th>
<th>Maintenance costs (€/ha/yr)</th>
<th>Harvesting costs (€/m³)</th>
<th>Land use before afforestation</th>
<th>Opportunity costs of land according to the fertility class of the soil (€/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver fir</td>
<td>3770</td>
<td>413 (year 1) 336 (year 2) 207 (year 3, 4, 5)</td>
<td>26</td>
<td>Arable land</td>
<td>725 (class I) 470 (class II) 300 (class III)</td>
</tr>
<tr>
<td>Walnut</td>
<td>4910</td>
<td>661 (year 1) 573 (year 2) 362 (year 3, 4, 5)</td>
<td>26</td>
<td>Pasture</td>
<td>700 (class I) 445 (class II) 255 (class II)</td>
</tr>
<tr>
<td>Beech</td>
<td>4750</td>
<td>620 (year 1) 542 (year 2) 362 (year 3, 4, 5)</td>
<td>26</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The benefits (Table 12) in this example include different subsidies for afforestation and maintenance. To cover the opportunity costs of land, in this case premiums are given to the farmer for 20 years. The premium covers 100% of the opportunity costs of land except for non-cultivated land (Tassone et al. 2004).

One advantage for the farmer may be the economic benefit if making use of marginal, less productive land, since forest can generally grow on less fertile soils than agricultural crops. Whether or not afforestation is a feasible option (and in that case what tree species may be used) will depend on local conditions such as climate and soil type, and most importantly, on availability of suitable land and land resources (Kearney, 2001). Barriers to afforestation for the individual farmer may furthermore include:

- a lack of knowledge, since forestry, similar to farming, takes specific practical and theoretical skills;
- a high initial cost for equipment, plant material and labour;
- traditions and cultural factors.

$^{12}$ For both arable land and pasture, a distinction is made according to three fertility classes in the soil. The afforested non-cultivated land was mainly previously abandoned land. Data for arable land refer to grain production.
The latter is not the least important point, since many farms are inherited through families. Changing from arable farming to forestry may therefore be a dramatic decision, as it breaks a tradition and often changes the landscape and settings for the farm.

Table 12  Benefits for private farmers from afforestation in southern Italy (Tassone et al. 2004)

<table>
<thead>
<tr>
<th>Type of plantation</th>
<th>Aids for afforestation costs (€/ha)</th>
<th>Premium to cover maintenance costs (€/ha/yr)</th>
<th>Timber sales (€/m³)</th>
<th>Land use before afforestation</th>
<th>Premium to cover opportunity costs of land according to the fertility class of the soil (€/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver fir</td>
<td>3623</td>
<td>310.90 (year 1, 2) 181.10 (year 3, 4, 5)</td>
<td>87.80</td>
<td>Arable land</td>
<td>724.50 (class I) 470.00 (class II) 300.00 (class III)</td>
</tr>
<tr>
<td>Walnut</td>
<td>4658</td>
<td>582.20 (year 1, 2) 349.90 (year 3, 4, 5)</td>
<td>206.58</td>
<td>Pasture</td>
<td>700.00 (class I) 445.00 (class II) 255.00 (class III)</td>
</tr>
<tr>
<td>Beech</td>
<td>4658</td>
<td>582.20 (year 1, 2) 349.90 (year 3, 4, 5)</td>
<td>87.80</td>
<td>Non-cultivated land</td>
<td>181.10</td>
</tr>
</tbody>
</table>

There are also a number of risks associated with afforestation projects, although these risks are not necessarily exclusive to forestry or afforestation. Risks include events which could have negative social and environmental impacts, and which may be of a natural, political or economical character. Natural risks include storms, fires, pests and diseases; political risks include uncertain property rights and policy changes; economic risks include exchange rate and interest rate fluctuations or changes in opportunity costs of land (Watson et al. 2000).

An important aspect of afforestation is the long timeframe for returns (of benefit and carbon net sequestration) associated with traditional forestry compared to many alternative land uses (such as crop production) (Thomas et al. 2010).

It is important to make clear in each case what the purpose and the prerequisites are for afforestation, since the interest may differ between stakeholders and the global view may be important. For example if (part of) the purpose is improving the ecological network, the spatial distribution of afforested land (and the linkages to existing woodland) as well as the tree species chosen are of importance. The afforestation may for example be part of or the Natura 2000 planning. Therefore, the actions should be followed by guidelines for the designation of afforested areas (Madsen, 2000).
6.4 Lessons learned

The present case study suggests that afforestation on average leads to constant or increasing total C storage, see section 6.3.

Out of the total C increase for the forest, the tree biomass contribute with the major C accumulation whereas the soil compartment, if including forest floor and mineral soil, can contribute with 0 to 30%. Forest floor C stocks tend to increase because of the litter fall from the trees. However, an increase in mineral soil C cannot be anticipated at all sites following afforestation of arable land. Nutrient poor soils according to this study accumulate more carbon than nutrient rich soils.

Key factors for the success of afforestation involve the right choice of management methods, the choice of wood species and the soil type, as well as the existence of a market for the wood products (including bio fuels). The changes in nutrient status as well as the economy of afforestation depend also on the land use before the afforestation (marginal land versus pasture or high-quality arable soil).

This best practice (afforestation) can potentially be applied in other European countries, although this case study has implications mainly for the oceanic, northern European climate. However, afforestation may have other types of advantages in arid regions, where shadow and water holding capacity provided by forests, as well as the reduced soil erosion or wind drift, may be important factors.

6.5 Policy Trade-offs

Mitigation programmes may directly or indirectly affect afforestation/forestry through including carbon sinks in the national greenhouse gas budgets, and increasing the market for renewable fuels. Afforestation of former arable land has been acknowledged under the Kyoto protocol as an activity that may decrease atmospheric CO₂. This case study strongly supports afforestation as a means to sequester carbon in the forest ecosystem. However, the effects of harvesting on the overall forest and soil carbon storage have not been discussed in this study.

The current Danish afforestation programme was introduced as part of a political response to an expected marginalisation of arable land. In previous decades, the purpose of such policies has been different. For example, in the 70s and 80s Danish politics were instead focused on expanding agriculture and policy instruments were therefore used to protect parts of the forest. Today, afforestation in Denmark is closely linked to the forests values for biodiversity, recreation and water protection (Madsen 2002).

Afforestation actions are linked to a number of policy fields. The EU Directive (2009/28/EC) on renewable energy¹³ and the Biomass Action Plan¹⁴ are relevant for afforestation, since wood can be used for renewable energy biomass. Changes in the EU Common Agricultural Policy (CAP) have had the result that important areas of agricultural land have been taken out of production. Much of this land is suitable for afforestation (DFLRI, 2001). Afforestation has been subsidised by the CAP, through Regulation (EEC) N° 1257/1999 (provision for aid scheme to promote afforestation to develop forestry activities on farms).

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Under the Rural development policy for 2007 to 2013 (Council Regulation (EC) No. 1698/2005) thematic areas affecting forestry and afforestation involve improving the competitiveness of the agricultural and forestry sector, improving the environment, improving the quality of life in rural areas and encouraging diversification of the rural economy. For example, a set of measures on training, information and diffusion of knowledge for farmers and forestry owners should be made available to achieve these goals.

Afforestation may furthermore work towards reaching the goals of other policy fields such as the Nitrates Directive (91/676/EEC) since the case study strongly supports afforestation as a way of reducing nitrate pollution of water bodies. However, as described in section 1.3, the effects of afforestation on water quality depend on forest management (Rosenqvist, 2007).

Depending on the geographical context of a country, afforestation may serve different purposes apart from improving SOM. For example, the Netherlands, Belgium, and Denmark all have a rather low percentage forest cover, and thus afforestation might substantially contribute to the reduction in CO2 net emissions. Similarly, the forests capacity or water quality improvement may be useful for example in regions of north-western Europe with high agricultural intensity and human population, experiencing problems with nitrogen pollution of ground and surface waters (DFLRI, 2001).

6.6 Future outlooks

Future amendments and increased demands for sustainability certification in the biofuel production may affect the way certain types of forest is produced, and thus the effects of afforestation compared to agriculture. The Directive 2009/28/EC also demand that the harvest of renewable energy must not affect the C stored in biomass or soil in a short perspective (20 years). A rapidly increased demand (and harvest) of forestry products may lead to risks of such a decrease. The development of the biofuel market is taking place fast and there may be risks involved due to the lack of experience in the new technologies. However, there is still a large demand for other types of wood products, which has increased steadily over the latest decades. The long time needed for C stores to build up in soil and ecosystems makes strategic planning extremely important, and may create a need for further policy interventions in the future.

6.7 References


Associated publications:


European Environment Agency, The European environment — State and outlook Copenhagen, 2005


Hansen, K. (Editor) (2002). Planning afforestation on previously managed arable land - influence on deposition, nitrate leaching, precipitation surplus, and carbon sequestration, Literature review for Afforest, - a project under the 5th Framework Programme


7.1 Context and aims of the case study

The project aims to manage and conserve four mires of national and international importance (Cena Mire, Stikli Mires, Klāņi Mire, Veseta River Floodplain Mire - Figure 26) by putting in place the activities set out in the Latvian National Programme of Biodiversity. The sites targeted in the project are Natura 2000 sites and include 14 habitats and 14 species listed in the Habitats Directive and 28 species listed in the Birds Directive. The project began in 2004 and was funded partly by LIFE.
Case study 7 Conservation of mires in Latvia

(LIFE04NAT/LV/000196). Practical results of this project include management plans, restoration measures, education and exchange of information.

The four peatlands in this project were damaged by drainage, peat extraction, intense forest management, road construction, etc., especially at their borders\textsuperscript{15}. Drainage has occurred all over Latvia between the 1930s and 1980s. In three of the project sites, drainage systems are still functioning\textsuperscript{16} and peat extraction continues in the area bordering the protected part of the Cena mire. One aim of the project is to manage the areas to reach a more favourable status of conservation.

Source: Project report 2006 and LPPA

\textit{Figure 26} \hspace{1em} Map of the project sites (top) and map of peatlands in Latvia (bottom)

\textsuperscript{15} The peatlands can be called mires (see definition in the introduction) as they present the structure of mires and continue to build up peat in the centre of the peatland. At the margins, problems of drainage imply that the peatlands are more degraded and it is more debatable whether they can be called mires.

\textsuperscript{16} Except in Veseta River Floodplain Mire.
Peatlands historically comprised 10% of Latvia's land area (IPCC, LPPA). Currently, just 4.9% of the total Latvian peatland area is in natural conditions and occupied by fen, transition or bog biotopes (LPPA). Drainage of peatlands has occurred to use lands for agriculture and forestry in a number of cases, and has been the highest pressure on peatlands (Maltby, 1991). Experience in peat deposit development, extraction and utilisation is extensive in Latvia, since peat extraction and utilisation have been early industrial activities, beginning in the 1930s (Kalnina et al., 2007). Peat extraction was an important industrial activity in the 1960s and 1970s in Latvia, where between 4.9 and 7.2 million tonnes of peat were extracted per annum. Extraction volumes in Latvia fell to 0.9 million tonnes per year in 2009 (LPPA).

In the more general context of European peatlands and European peat production, Latvia holds 2% of EU peatlands17,18. Latvia produces 6% of EU peat production for all usages (in m³), which include mainly energy usage (50%) and use as a growing media (for horticulture for example) (42%) (EPAGMA, 2007). Latvia was estimated, in 2008, to be responsible for the emissions of 4.22 Mt CO₂/year from degrading peat (through land-use changes and peat extraction) (Wetlands International, 2009). Peatlands of Latvia are estimated to store 490 Mt of carbon (Christensen and Friborg, 2004).

The project was implemented by a conservation NGO, with the purpose of conserving an important natural heritage in Latvia. Peat extraction, but also drainage of the mires for agriculture or forestry, has highly affected natural raised bogs in Latvia. The Cena Mire (one of the protected mires in this project), which was the second largest bog in Latvia, covered 10 600 ha before peat extraction began. Drainage activities began at that site in 1933 and peat extraction was initiated in 1940. Currently, 2 133 ha remain as a protected area (Kalnina et al., 2007a, EEA Natura 2000 Viewer). The project has ensured raised water levels at that mire, which have helped to reintroduce functioning hydrological cycles in the mire and the growth of wild species again, thus restoring to a certain extent the biodiversity.

Positive outcomes of the project include:

- Elaboration of management plans for each mire;
- Restoration of the hydrology of the mires by building dams and removing shrubs and pines;
- Inventory of biodiversity at the project sites, including recovery of certain species of importance at EU level;
- Education, awareness-raising, communication towards the broad public and stakeholders; and
- Exchange of information between peatland experts.

**Table 13 Maximum peat depth in the protected mires**

<table>
<thead>
<tr>
<th>Mire name</th>
<th>Cena Mire</th>
<th>Stikli Mires</th>
<th>Klāņi Mire</th>
<th>Veseta River Floodplain Mire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal peat depth</td>
<td>5,75 m</td>
<td>n.a.</td>
<td>4 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Area protected</td>
<td>2 133 ha</td>
<td>6 636 ha</td>
<td>1 615 ha</td>
<td>427 ha</td>
</tr>
</tbody>
</table>

17 As a comparison, Latvia covers also about 2% of the EU territory.
18 For a discussion about how to evaluate the distribution of peatlands in Europe, see Montanarella et al. 2006.
7.2 The Best Practice management method

Before the project, a mire inventory had been performed in Latvia, which ensured that the selection of the sites and the measures to be taken to protect the sites were based on expert information.

The goal of the project was the protection of the mires and the realisation of management activities set out in Management Plans (which had to be drafted). However, before protection and management could be realised, further desiccation had to be prevented. Dams were used to reinstall the hydrological cycles vital for the functioning of the mire and undesirable vegetation was removed to favour species typical of mire habitats.

Another important step of the project was to raise awareness among stakeholders and the broad public on the importance of protecting mires in order to ensure long-term protection of the mires and to limit uncontrolled recreation activities that have negative impacts on the mires, such as trampling, hunting, fishing, vehicle damage from off-road vehicles, etc. A wide range of communication activities were implemented to reach this goal, including nature trails, watch towers, producing leaflets, information boards and audio-visual communication materials, organisation of school tours, etc. The management plans thus involved building dams, cutting unwanted vegetation and monitoring the success of the actions. Currently, no specific actions are implemented at the site since the end of the LIFE project. The management plans have considered the influence of human activity, of drainage but have not foreseen measures to protect the mires from climate change.

The first step of the project included raising stakeholder awareness around the mires, including municipalities, private companies, forest services, etc. This step enabled them to become interested in the project, as they understood that it would bring positive results, including in terms of communication around mires and biodiversity, through the nature trail and other communication components of the project (booklets, film, etc.). A private company involved in peat extraction in a close area also took part in the project, as they realised that protection of peatlands is important. The role of the municipalities in the project was mainly to finance the restoration works, while certificated companies built the dams, and to finance the communication tools.

Exchange in experiences were successfully carried out in this project as the lack of expertise in hydrology was overcome by study tours and contact with experts – the dams built in this project had never been implemented in Latvia before. Studies in Ireland and Finland were used to build knowledge of Latvian experts, as they have long-term experience and several studies were performed (e.g. Heikkilä and Lindholm, 2006, van der Schaaf and Streefkerk, 2003, Tuittila et al., 2000, Money and Wheeler, 1999, Lode, 1999). Dams used in this project are created by excavators and built using peat from the margins of the ditch, but a diversity of materials has been used in previous projects (e.g. wood, plastic) in many countries (e.g. Germany, UK, Estonia, Lithuania, Poland, France, Sweden) (Pakalne, pers. comm.). The project could thus benefit from previous experiences and the technique used has been rated as successful to restore peatlands. The International Mire Conservation Group was also a useful network to be used to obtain and diffuse information.

The mires now seem to have quite a large public of visitors, which enjoy the nature trails and watch towers (Pakalne, personal communication).
No specific data is available from the sites on gas fluxes themselves as only hydrological and biodiversity monitoring was implemented as parts of the project. According to the site managers the monitoring of the vegetation showed a quick regrowth of sphagnum in particular, which is one of the main factors responsible for peat formation. The water table rises very quickly once the dams are built (Pakalne, personal communication). Restoring water flows ensures the regrowth of vegetation which allows the buildup peat (even if at a very slow rate: virgin peatlands take up carbon at rates between 0.1 and 0.3 t C/ha/year, Freibauer, 2004); and most importantly reduces carbon emissions from peat use for energy purposes and from peat oxidation (peat oxidation releases carbon at a rate of 2.2 to 5.4 t C/ha/year, Freibauer, 2003). Some restored boreal bogs have become net C sinks again following successful re-establishment of sphagnum-dominated vegetation (Strack, 2008). Carbon sequestration fluxes are estimated for Northern EU countries to reach around 20 g C/m²/year (Roulet, 2000\textsuperscript{19}). Rewetting peatlands was shown to cause significant rises of CH₄ fluxes (Komulainen, 1998): in a study in southern Finland, during the 3 study years methane emissions at the control plots of the fen site rose with rising water table after rewetting from 0.1 g/m²/year to 2.1 g g/m²/year. At control plots of the bog site CH₄ emissions increased from 0.8 g g/m²/year to 4.6 g/m²/year. However, most field investigations of peatland restoration have been too short to evaluate the long-term dynamics of rewetted mires. Current scientific knowledge recognises three phases of carbon and nitrogen cycling, and only in the third phase, after more than 10 years, are greenhouse gas fluxes expected to be in the range of natural peatlands. Thus initially, restoration may result in increased GHG emissions, but in the long-term the peatland should return to a C and GHG sink with a similar climate impact as an undisturbed peatland (Strack, 2008).

\textsuperscript{19} Depending on the authors cited, it varies between 8 and 23 for Finland, Estonia, USA, to 25.5\textpm{0.5} in Finland bogs, 17.2\textpm{0.3} in Finland fens, and 36 to 45 in ombotrophic peatland in North Sweden.
### Table 14 Average Emission Factors Based on Measured Fluxes from Bogs and Fens under Different Management Types from European Peatland (Strack, 2008)

<table>
<thead>
<tr>
<th>Type of management</th>
<th>CO₂ (kg C/ha/yr)</th>
<th>CH₄ (kg C/ha/yr)</th>
<th>N₂O (kg N/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bog (ombrotrophic)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td>2 350</td>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td>Arable</td>
<td>4 400</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Restoration</td>
<td>620</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Fen (minerotrophic)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td>4 120</td>
<td>0.4</td>
<td>5.05</td>
</tr>
<tr>
<td>Arable</td>
<td>4 090</td>
<td>-0.2</td>
<td>11.61</td>
</tr>
<tr>
<td>Restoration</td>
<td>-</td>
<td>12.4</td>
<td>0.64</td>
</tr>
</tbody>
</table>

#### 7.3 Best Practice Trade-offs

The sites are Natura 2000 sites and as such protected areas. They were already nationally protected areas before the entry of Latvia in the EU. Peatlands correspond to a high part of Latvia’s land, and out of the 327 Natura 2000 sites (EEA Natura 2000 Viewer), around 140 include peatlands or mires (Pakalne, pers. comm.). However, as described above, outside of the protected areas, peat extraction took place, reducing the size of mires in Latvia.

Protecting peatlands is very important as mires absorb CO₂ and store it for a very long time as peat. Peatlands protection conserves the CO₂ (and avoids N₂O emissions) in the soils. Furthermore, peatlands include²⁰: Active raised bogs (7110*), Degraded raised bogs still capable of natural regeneration (7120), Bog woodland (91D0*), Transition mires and quaking bogs (7140), Natural dystrophic lakes and ponds (3160), which are habitats for a number of species and protected as such through the Habitats Directive in the EU. At the sites of the project, 59 species listed in the Habitats and Birds Directive were found (Project report, 2006). Lastly, mires provide ecosystem services linked to their role in the water cycle.

The private company taking part in the project is cutting peat at the edge of the protected area of the Cena mire. No information is available on whether this situation has any impacts on the protected area. However, the protected areas seem to be in a good conservation status, thanks to the raised water level after dams were built. Before the implementation of the project no peat cutting existed at the other sites and thus no direct displacement of peat cutting occurred because of the established protection. However, peat cutting is an on-going activity in Latvia in other areas.

#### 7.4 Lessons learned

Restoration of mires is complex and multi-disciplinary. Careful planning of restoration techniques, scientific and technical knowledge as well as clear objectives are thus important to ensure success of the restoration works (Kalnina et al., 2007).

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²⁰ Number in brackets refer to the Habitat code in the Habitat Directive.
Rewetting mires is often needed to ensure their protection and conservation of their functions. This project provides a good example of how to raise water levels by building dams. In terms of biodiversity protection also this method seems successful as a lot of species invaded the protected peatlands, which increased biodiversity. However, the situation of each mire to be restored need careful examination before management or restoration practices are undertaken, as each project has its own issues and solutions. Monitoring of the vegetation of the hydrology at the sites is carried out, and results are available in the reports compiled for LIFE. However, no monitoring of carbon storage has been performed on the sites. As it is known that carbon is stored only very slowly in peatlands, evaluating the impact of the protection of peatlands in storing carbon is difficult. However, it ensures no further degradation occurs, which would release carbon rapidly in the atmosphere.

Two communication best practices are illustrated through this project:

- Productive exchange of experience between EU country experts; and,
- Positive outcomes of the nature trail and other communication tools towards the broad public.

Among others, two communication tools are particularly interesting for future projects to use in order to capitalize the expertise gained in previous projects:

- The book published in 2008 “Mire Conservation and Management in Especially Protected Nature Areas of Latvia” which contains management and monitoring guidelines as well as information on habitats and species, gained from this project; and,

7.5 Future outlooks

The project has broad use possibilities across the EU and has already been implementing lessons learned in the framework of restoration projects in the EU, using exchange of experiences and visiting other restored sites in order to use best available techniques. Restoration was however only the initial step of the project, which is aiming to protect the mires on the long term and ensure good management of the mires, especially for biodiversity conservation, but with the storage of carbon as a beneficial effect too. The protection of the mires should ensure that peat continues to be formed, thus increasing the carbon stocks in the soils.

The involvement of peat companies in the restoration of mires is an important step towards raising awareness of the peat industry representatives about the need for the restoration activities in the site after extraction has ended (Silamikele and Pakalne, 2007).

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21 In particular, the background paper “Wetland management methods in protected nature areas and their application in LIFE-Nature projects” (see footnote 23) provides different solutions for different peatland projects.
22 The book (both in English and Latvian) is available from: www.ldf.lv/upload_file/29137/Purvu_gramata.pdf
23 The background paper is available from: www.bef.lv/data/file/BP_wetlands.pdf
CASE STUDY 8. RESTORATION OF BOGS IN IRELAND

Box 1: Basic Data

Location: Ireland - 20 sites for the blanket bog project (1), 14 sites for the raised bog restoration project (2)

Biogeographical region: Atlantic region

Time: (1) 2002-2007 and (2) 2004-2008

Initiator: Coillte Teoranta (The Irish Forestry Board)

Objectives: Restore raised/blanket bogs, increase current knowledge in the area of afforested bogland restoration, diffuse information through demonstration sites.

Bibliography: www.raisedbogrestoration.ie/about-raised-bog-project.html#summary
www.irishbogrestorationproject.ie

Key expert: Philip Murphy, Michael Delaney, Angela Wallace and Pat Neville
Philip.Murphy@coillte.ie +353 44 9342744
8.1 Context and aims of the study

This case study introduces two projects of peatland restoration in Ireland, performed by Coillte (The Irish Forestry Board\textsuperscript{24}). One project aims to restore raised bogs and the other project blanket bogs\textsuperscript{25}, mainly on Special Areas of Conservation (SAC, designated under the EU Habitats Directive\textsuperscript{26}). In Ireland, habitats which should be protected through SACs include raised bogs and blanket bogs. Currently, SAC areas cover approximately 13 500 square km (NPWS, undated) in Ireland. Peatlands in Western Ireland are among the most important intact areas of active blanket bog found in Europe (i.e. still peat-forming or growing).

Coillte is a state-sponsored commercial company operating in forestry, land based businesses, renewable energy\textsuperscript{27} and panel products. Coillte developed a nature conservation strategy since 1999, which includes a commitment to habitat restoration, of which the peatland restoration projects are a part. Both projects were supported by EU LIFE funding (LIFE02 NAT/IRL/8490 and LIFE04 NAT/IE/000121).

Peatlands in Ireland take the form of bogs and fens. The bog is one of Ireland’s most characteristic features. Bogs cover about one sixth of Ireland (1 200 000 ha), a higher share than any country in Europe except Finland. Bogs are exploited for several centuries for fuel, reducing the peatland areas in many European countries. In Ireland industrial scale exploitation over the past 70 years has greatly contributed to this reduction. Ireland has now importance for conserving bogs (Abott, undated). Two distinct types of bogs exist:

- Blanket bogs, expansive, generally formed in wet or upland areas, are found typically in western Ireland and also in mountainous areas; and
- Raised bogs, smaller, generally formed in lowland areas, and are found almost exclusively in central Ireland (the Midlands).

\textsuperscript{24} www.coillte.ie
\textsuperscript{25} See definitions at the beginning, bogs are specific types of mires.
\textsuperscript{27} Mainly wind energy
In Ireland - as in most countries in the world - peatlands have been used for cutting peat (called 'turf' when cut), or drained for creating grazing areas or to plant trees (afforestation). This led to the destruction of large amounts of peatlands. In the Republic of Ireland, there has been a 92% loss of raised bogs, and a 82% loss of blanket bogs (IPCC, 2002). Awareness of the importance of peatlands in terms of carbon storage, but also landscapes and biodiversity is increasing and restoration and protection are now increasing. Ireland is in a unique position in Europe in that it possesses almost 200 000 ha of actively growing raised and blanket bogs and fens which are of increasing European conservation importance (IPCC, 2002). The case study presented here provides an example of two restoration projects.

From a broader European perspective, Ireland accounts for 4% of EU peatland areas and produces 21% of peat production for all usages (EPAGMA, 2007). Peatlands in Ireland are estimated to store 947 Mt of carbon (Christensen and Friborg, 2004). Peat extraction used for energy is still a great use in Ireland (4.7 million tonnes, third after Finland and Russia in Europe) (Joosten et al., 2002).

The projects aim to:

- restore 571,2 ha of raised bog on 14 sites predominantly in the central plain of Ireland to a favourable conservation status to extend the area of raised bogs and to increase knowledge about restoration of bogs on afforested sites; and,

- restore up to almost 2 000 ha of blanket bog on 20 sites to a favourable conservation status; and, in particular, to extend the area of blanket bog on these sites by means of tree removal, enlarging it by up to around 1 000 ha.

Both projects serve as a hands-on demonstrations of the best approaches to restoration of bog habitats.
Programmes of reforestation were put in place in Ireland in the 1900s to counter exploitation of native woodlands deforestation practices for agriculture. Agricultural lobbies pushed to ensure that reforested areas were confined to areas less suitable for agriculture, including bogs, which were often regarded as wastelands. Today, in recognition of the loss of peatlands across Europe and in Ireland, new management options emerge, one of them being restoration of peatland habitats, where suitable. The first project was launched in 2002 and the second in 2004, to provide hands-on experience and flagship demonstration of restoration practices for bogs.

Today, the Coillte estate comprises a total raised bog area of 31,815 ha of which 6,496 ha are virgin raised bog. The restored areas are parts of SACs and will be managed for biodiversity conservation purposes. The second LIFE project was implemented in the framework of the FSC certification and following the success of the first restoration project.

8.2 The Best Practice management method

The projects aim to restore bogs owned by Coillte, to ensure a good conservation status and conserve carbon stored in the soil; both include demonstration sites to raise awareness and exchange experience on best practices. In both cases, most areas had been afforested for socio-economic reasons. Two main steps are thus the removal or felling of tree plantations and the blocking of forestry drains to restore water levels and facilitate the growth of bog vegetation. Coillte selected for both projects the sites with best nature conservation value, based on the evaluation of an ecologist who monitored the sites. Criteria for the selection also included the fact that the areas were in Natura 2000 designated sites and that areas where rights to cut peat for fuel were granted were not selected and not close to selected areas, in order to avoid conflicts.

In the project restoring blanket bogs, four types of felling were used:

- Fell to waste, in which case conifers felled were simply left at the location. The technique is inexpensive but as much tree material is left on the ground, recovery of bog vegetation will be slowed down.
- Fell and windrow, where felled trees are put in long lines (windrows) using an excavator. Regeneration of vegetation is much enhanced through this technique, at most sites purple moor grass (Molinia caerulea) achieved 90% ground cover within 2 years of felling.\(^{28}\)
- Fell and chip, to enhance degradation of woody material, allowed good regeneration of bog vegetation, but is time consuming, very expensive and limited in wet conditions, so the technique was abandoned during the project.\(^{29}\)
- Commercial felling, which can be interesting economically, but recovery of the blanket bog habitat is slow.

Another action put in place was the installation of dams. This activity involved blocking drains on nearly all of the project and extension sites. Both plastic and peat dams were used depending on the sites. Expenditures on infrastructures on durable goods (infrastructure and equipment) were around 225,000 Euros in the raised bog restoration project and was much less than expected as peat dams were more used than plastic dams, which are more expensive in the raised bog project. Peat dams were installed to treat more than 302 ha. In order to ensure no overgrazing occurred and to restore the sites to a favourable state of conservation, fences were erected or repaired. Lastly, in order to ensure the project was successful, removal of certain natural

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\(^{28}\) The remaining 10% could more or less correspond to the size of the area where trees were windrowed, according to one of the project managers. Fell and windrow was the most effective technique in terms of how quickly peatland vegetation re-grows.

\(^{29}\) The abandonment of the technique was decided in coordination with the monitoring team from LIFE+.
regeneration of non bog type species, including regenerating conifers was needed and monitoring of water levels and vegetation was carried out to assess the project’s success.

Based on the results of the first project, the second project used fell and windrow as well as commercial felling for restoring the raised bog. Dams installed included both mechanically installed peat dams and manually installed plastic dams. Based on the first experience, plastic dams were installed on selected sites which were not suitable for peat dams in the second project. Fencing to ensure protection of the sites was implemented, as trampling can cause damage to the regenerating bog vegetation and can damage dams. Removal of regenerating non-bog vegetation was cleared, and monitoring of water tables and vegetation was undertaken.

Fell and windrows techniques were reported to cost around 222 000 Euros, harvesting 53 000 Euros, dam installation 200 000 Euros, fencing 15 000 Euros, road building 4 500 Euros and dip wells installations 22 000 Euros. These costs include material, personal, consumables, travels, etc. and are reported for the raised bog project after 2 years of project implementation. 225.6 ha was felled and windrowed, 196.4 ha were harvested, dams were installed on 219.5 ha, fences erected on 5 120 m, and 122 dip wells had been installed. Regarding biotope management, around 13 500 Euros were spent on removing natural regeneration, 12 000 on vegetation control, etc.

The expenses show that restoring afforested peatlands is very expensive and needs a lot of time and personnel (personnel expenses reach more than half a million Euros, i.e. more than half of the budget spent after 2 years of programme). Without support from the EU through the LIFE programme, Coillte reports that it could not have implemented such works (LIFE reports). Thus financial incentives and support are key to the success of peatland restoration.

The technique of wind-rowing of conifers was reported to be substantially cheaper than chipping: €1000-1500/ha as compared to €3000/ha.

Both projects were implemented by Coillte without partners, but the local populations were involved as much as possible. Land managers (training) days were arranged and bog walks organised. At demonstration sites, interpretative display signs are available to explain the objectives and details of the project. A public awareness programme was launched at these sites.

Consultations formed a main part of both projects and many exchanges occurred in particular with other LIFE projects. The Irish Peatland Conservation Council (IPCC) were very complimentary towards the work which was completed by the blanket bog project.

8.3 Best Practice Trade-offs

The areas were cleared of forests where commercial harvesting was taking place. Restoration means that such activities will not continue. Further areas in Ireland could be restored for blanket bogs in Western Ireland, but less for blanket bogs (see 3.6).

On the other hand, restoration underlines the environmental responsibility of Coillte, demonstration sites promote public awareness of the importance of bogs and integrates positively the framework of the FSC certification from Coillte (see below). Coillte underlines however the price of restoring bogs and the need to secure funding to implement such projects.
In the raised bog project, on some project sites, perimeter drains could not be blocked as this would have adversely affected peat cutting rights on adjoining areas outside the project.

8.4 Lessons learned

On the restored sites, the recovery of blanket bog vegetation was evident, which is a very positive sign showing initial success of the project. Vegetation monitoring documented changes in vegetation for the first 3-4 years after restoration. The colonisation depends on age of the plantations felled. In areas were young plantations were felled, the main species to recolonise and spread is *Molinia caerulea* with the shrub *Calluna vulgaris* also locally common. In areas where older plantations were removed, the vegetation recovery has been much slower with mosses such as *Hypnum cupressiforme* and *Polytrichum commune* typically dominating. Further monitoring will be needed to ensure continuation of the process, which will be ensured by the After-LIFE plan. Important information on recolonisation of the bogs by typical vegetation will be gathered through this project, which may be used for scientific and practical purposes in the future.

Different techniques were tried out during the blanket bog restoration project. As regards tree felling, chipping and killing a conifer crop standing is regarded as the least interesting techniques due to the relatively high cost and the time needed. Windrowing felled trees is assessed as an ecologically effective and cost-effective way of clearing the majority of the bog surface of tree cover. Felling to waste was considered a better option if using machinery would have caused damage to the sensitive bog vegetation, but is not used on other sites as leaving dead tree material on the ground retards the recovery of bog vegetation. Windrowing the trees on the opposite allow the vegetation to recover more rapidly. At sites where this technique was used, in certain sites 90% ground cover was achieved within 2 years of felling, especially by purple moorgrass (*Molinia caerulea*). Fell and chip has the same advantages in recolonisation, but takes more time and was thus regarded as less advantageous.

For drain blocking, the conclusion is that peat dams should be favoured for cost reasons, but in very hydrologically sensitive areas or for wide drains plastic dams may still be the best option. Plastic dams were thought to be interesting at the beginning of the first project as it was a technique used in other sites and was reported to be efficient. However, the use of peat dams was considered more cost-effective during the project implementation phase, especially due to the high price of plastic dams. Plastic dams were reported to cost around 30€ (material and labour), while a peat dam would cost 2-3 Euros (LIFE report) for dams that are at most around 1 meter wide. Calculating the price of individual dams is however difficult, as peat dams will be installed with the use of an excavator while plastic dams may be installed manually with a hammer. Other sources report that plastic dams can cost over £30 000 per km, against £ 7 000 per km for peat dams (Worral et al., 2007). Both types of dams are blocking drains effectively, but need quite a lot of checking to ensure no repairs are needed. Certain areas are more suitable to peat dams, e.g. where vegetation is rooted deep or in dry areas, in which plastic dams are difficult to install. In other areas peat dams cannot be installed, e.g. in wet areas where excavators cannot access. Plastic dams also mean that non-natural material is used in the restored areas. Peat dams are recognised to be quite solid, especially when bog vegetation grows on them and limits erosion.

During the raised bog restoration project, lessons learned in the previous project were implemented: windrow felling and commercial felling were used and plastic dams were used only in specific locations. In the second project, water quality monitoring was more developed to address concerns of the potential of bog restoration measures and
to address information gaps in the area. In particular, the site managers wanted to monitor whether nutrient levels rose when trees were felled and how long initial nutrient levels took to go back to normal. Restoration measures were found to impact the areas with differing extent in the short-term, but within two years baseline water quality would be attained or even surpassed. Additionally, in the second project firelines were installed to reduce the risk of fires.

In terms of re-vegetation, colonisation began at all sites, and the main factor for recovery seems to be the age and yield class of the conifer crop which was removed. Closed canopy areas are slower to recover, thus the prospects of recovery are better if the area can be restored before the trees have grown tall (see above on the species present depending on the age of the plantation).

The hydrological functioning of the sites has shown to recover positively. The blanket bog restoration project showed however that it is a very slow process, thus in order to reach pre-drainage levels, decades will probably be needed.

8.5 Policy Trade-offs
Both projects are LIFE projects, aiming to restore mainly SAC areas owned by Coillte, supporting the objective of protecting peatlands, as valuable biodiversity habitats and carbon stocks. The projects allowed restoring and improving the conservation status of more than 1,989 ha of priority active blanket bog habitat and more than 571 ha of Raised bog (active) and Degraded raised bog habitat.

Peat cutting for fuel and energy independency
Peat cutting began in the 17th century and increased until the mid 20th century. In 1934, the Turf development Board was created which bought land under compulsory-purchase orders and cut turf. Half of Ireland’s raised bogs were destroyed (at a rate of 800 000 tons per year) between 1814 and 1946. Bord na Móna continued the process after World War II and in 1969, 100 000 ha of raised bogs were left in Ireland. Cutting also destroyed about 15% of blanket bog in the Irish Republic, and 50% in Northern Ireland (Abott, undated). Peat from blanket bogs being of lesser quality than that from raised bogs, blanket bogs were relatively less harmed by peat cutting. Peat is an important strategic energy reserve in Ireland, so political support to the industry can still be envisaged (Christensen and Friborg, 2004).

In the blanket bog restoration project, peat cutting did not seem to have an impact on the work performed, but in the raised bog restoration project some drains could not be blocked as it would have impacted adjacent sites where peat was cut. A derogation given in 1999 exists to continue peat cutting on some SACs. A list of SaCs on which peat cutting is now forbidden has been published and the remaining derogations are expected to cease in the next year.

Afforestation policies in Ireland
In recent years, peatlands in Ireland were drained and blanket bogs were used for the planting of conifer plantations. Indeed, Ireland has one of the lowest percentage of forested land in the European Union30, and the large scale development of conifer plantations has been one way of trying to increase forest cover and domestic timber resources. Currently, reduced government grants were designed to help decrease this practice (Abott, undated). Afforestation is still supported in Ireland, but the recognition of nature values, especially in peatlands now means that peatlands will not be afforested anymore.

30 Ireland had 710ha of forests in 2005, i.e. 10% of the total land area. Malta is the only country with less forest percentage with 0.9%. (Eurostat, 2010)
Protection policies

In recent years, awareness of the importance of bogs for science has increased. In the Republic of Ireland, there are plans to set aside 10,000 hectares of raised bog for conservation purposes. In Northern Ireland, which has less raised bog to begin with, almost all raised bogs are being preserved as Areas of Special Scientific Interest (Abott, undated).

In Ireland, no new peat mining areas will be developed. Changes to the Common Agricultural Policy have stimulated a move towards more environmentally friendly agricultural practices as well as efforts to reduce agricultural production. This has reduced the pressure to drain peatland for agriculture. This is supported by national schemes in many member states. Peatland restoration is likely to increase in the future as peat extraction ceases in many areas and as unproductive forest drainage areas are restored (Christensen and Friborg, 2004).

8.6 Future outlooks

The techniques that were used or developed during the projects (e.g. windrowing of timber felled to waste, plastic/peat damming of drains) have clear potential for transfer within Ireland and other Member States, according to Coillte. Techniques that are used, to fell trees or to block drains, are not highly technical activities, and can be developed in any afforested peatland in principle. The project has been visited, in this context, by the IPCC and by LIFE project leaders from Ireland, Northern Ireland, England, Scotland, Finland and Wales (after project end). The five demonstration sites also acted as flagship demonstration of restoration techniques, subject to availability of funding. The project team was approached by NGOs and community groups to obtain advice on restoration techniques and help was provided as much as possible. Coillte also worked for the National Parks & Wildlife Service to restore bogs owned by the State.

Many blanket bog areas are still remaining in West Ireland which could benefit from restoration work, provided financing is available. The situation for raised bog is quite different. Coillte will implement a new LIFE project in 2011 to restore further raised bog areas, which will mean that most of the raised bog areas Coillte owns will have been restored.

Coillte underlines the importance of securing fundings for the restoration of bogs, through e.g. the Rural Development Programme or LIFE. The site managers report that restoration projects of this scale could not have been afforded without this financial support. The spent budget for the blanket bog restoration project was just above € 4 million, while it was just above € 2.3 million in the raised bog restoration project. More detailed numbers are detailed above, but this shows that for two areas of respectively 1,989 ha of blanket bogs to be restored and 571.2 ha of raised bogs, large funding amounts are needed. The restored areas will be protected as SACs or other protected areas and in the framework of the FSC certification of Coillte (see next section).

Coillte secured FSC certification of its forests, and in this context, an ecological survey identified 15% of the estate to be managed primarily for biodiversity. The conservation of the restored areas will be ensured in this context. The restoration of the peatlands is expected to facilitate the colonisation of the areas by Annex I species (EU Habitat Directive). It also maintains carbon stocks in the soil. The scientific information gathered through vegetation monitoring could be used in the future to inform a strategy for blanket bog restoration in Ireland or more generally.

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31 Irish Peatland Conservation Council
32 Forest stewardship council, see www.fsc.org/
Information on water tables was also gathered. In pristine bogs, water should remain within 10 cm of the surface. During the projects, once trees were cut, an increase in water tables is seen, as well as when drains are blocked. Apart from checking that dams are effective, no further measures are taken to enhance the restoration of hydrological functions and no specific possibilities seem to emerge either for quickening the process.

However, no information on the amounts of carbon stored in the soils or the exchange of gases in the peatlands was performed. In this sense, the only qualitative assessment to be made is the fact that peat is a form of organic matter and peatlands are a space-effective way of storing carbon in the soils (Verhagen et al., 2009). Restoration of the bogs thus should ensure, together with the long-term protection of the restored areas, continued storage of carbon in the soils. Peat depth in blanket bog habitats is between 2 and 6 meters and in raised bog habitat can reach up to 12 meters (IPCC, 2002).

Coillte has not implemented a specific monitoring of carbon stocks on the sites, but rather concentrated on the water table height as well as vegetation regrowth, including ensuring that the sites are maintained and monitored in the future. For the moment, no measures are taken to tackle climate change impacts on the restored sites.

The role of the EU in co-financing the projects is acknowledged by Coillte as crucial in the success of the project. Furthermore, the advice from the LIFE monitoring committee was helpful and professional. The exchange of good practices between LIFE projects also provided useful information and ensured successful techniques were shared. The fact that LIFE does not require long-term continuation is seen as an area for improvement and possibly financing or helping financing long-term activities would be welcome, both by the managers and for ensuring long-term environmental benefits.

Peatlands restoration and protection ensure that the GHG emissions are reduced, as drained peatlands emit more gases than peatlands in their natural state. However, time is needed for restored peatlands to fully recover their initial emission rates. Peatlands are a space-effective way to store carbon and provide many further services such as habitats for biodiversity, water filtering, water retention.

Methods for felling afforested peatlands (Irish case study) and to block drains (both case studies) are not highly technical and can be used in many other areas. In Western Ireland in particular many blanket bogs remain that could be restored. Financial support is however needed to develop large scale restoration.

The most effective way to ensure that carbon is stored in peatland soils is however to reduce land-use changes (to agriculture and forestry) and peat use (for energy and horticulture).
8.7 References


Christensen and Friborg (2004) EU Peatlands: Current Carbon Stocks and Trace Gas Fluxes, Discussion paper originated from a workshop in Lund, Sweden, October 2003, a contribution to the project Concerted Action CarboEurope-GHG which is part of the CarboEurope Cluster.

Coillte website: www.coillte.ie


International Mire Conservation Group www.imcg.net/


33 2007a refers to the power point presentation and 2007 to the summary text presented at the Conference.
after peat extraction: which issues for tomorrow?, held in Lamoura (France).
Information available from www.pole-tourbieres.org/Actes_Colloque.htm#rehabilitation


Latvian Environment Agency – Mire biodiversity
www.lva.gov.lv/daba/eng/biodiv/purvu_e.htm

Latvian Fund for Nature www.ldf.lv/pub/?doc_id=28164


Case study 8 Restoration of Bogs in Ireland

Peatlands and carbon flows - Outlook and importance for the Netherlands

