Impact of clear-cutting and selective cutting on the soil-atmosphere greenhouse gas exchange of an N-saturated spruce forest in the course of its conversion to a mixed deciduous forest

N. Brüggemann, R. Gasche, H. Papen, Stephan Thiel, Georg Willibald, K. Butterbach-Bahl

Forschungszentrum Karlsruhe (Karlsruhe Institute of Technology)
Institute of Meteorology and Climate Research
Atmospheric Environmental Research (IMK-IFU)
Garmisch-Partenkirchen
Germany
Research question

How do different forest conversion practices (clear cut, selective cutting) affect N cycling in an N-loaded spruce forest ecosystem?
Experimental site: Höglwald
Location of the different experimental sites in the Höglwald

Selective cutting 2000/2006

Spruce control

Clear cut 2000
Höglwald characteristics

<table>
<thead>
<tr>
<th>Forest:</th>
<th>Approx. 100-yr-old spruce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation:</td>
<td>540 m.a.s.l.</td>
</tr>
<tr>
<td>Mean annual temperature:</td>
<td>7.7 °C</td>
</tr>
<tr>
<td>Mean annual precipitation:</td>
<td>933 mm</td>
</tr>
<tr>
<td>Humus type:</td>
<td>Moder (~7 cm)</td>
</tr>
<tr>
<td>Soil type:</td>
<td>Typic Hapludalf (USGS)</td>
</tr>
<tr>
<td>pH in CaCl₂:</td>
<td>&lt; 3 (organic layer)</td>
</tr>
<tr>
<td></td>
<td>&lt; 4 (A horizon)</td>
</tr>
<tr>
<td>Wet N deposition:</td>
<td>~30 kg (NH₄⁺:NO₃⁻ = 2:1)</td>
</tr>
</tbody>
</table>
Experimental areas

Spruce control
Control site without treatment (last thinning 1975)

Selective cutting
Area of 1 ha with selective cutting in 2000 and 2006 (removal of c. 20 % of the trees each time)

Clearcut
Area of 1 ha, clear-cut in 2000 and planted with beech

Start of the experiment: July 1999 (pre-treatment phase)
Cutting: End of February 2000, 2006
N input via throughfall

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>30.1</td>
<td>20.9</td>
<td>25.9</td>
<td>25.6</td>
</tr>
<tr>
<td>Selected cutting</td>
<td>24.2</td>
<td>17.4</td>
<td>24.5</td>
<td>22.0</td>
</tr>
<tr>
<td>Clear-cut</td>
<td>14.8</td>
<td>11.5</td>
<td>10.4</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Nitrate in seepage water

\[ \text{NO}_3^- \text{ [\mu mole l}^{-1}\text{]} \]

Nitrate concentrations in seepage water (40 cm depth)

- **enhanced** under the clear-cut area in the first and second year after the treatment

- **lower** in the third year as compared to the control and selective cutting area.

Soil N$_2$O fluxes since July 1999

- **Spruce control**
- **Selective cutting**
- **Clearcut**

Cutting

N$_2$O emission [µg N m$^{-2}$ h$^{-1}$]

Soil N$_2$O fluxes since July 1999

Huge N\(_2\)O emission during thawing

N\(_2\)O emission [µg N m\(^{-2}\) h\(^{-1}\)]

Spruce control
Selective cutting
Clearcut

Jan 2006
Jan 2007
Freeze-thaw effect 2006 Höglwald spruce

Soil temperature [°C]

-10
-8
-6
-4
-2
0
2
4
6
8
10

N$_2$O emission rate [µg N m$^{-2}$ h$^{-1}$]

0
100
200
300
400
500

$t_{ol}$
$t_{5cm}$
$t_{10cm}$
$t_{15cm}$
t$_{20cm}$
t$_{air}$

date

2.1.06  16.1.06  30.1.06  13.2.06  27.2.06
Soil CH\textsubscript{4} fluxes since July 1999

- Spruce control
- Selective cutting
- Clearcut

CH\textsubscript{4} deposition [µg CH\textsubscript{4} m\textsuperscript{-2} h\textsuperscript{-1}]

Soil CH\textsubscript{4} fluxes since July 1999
Soil CH₄ fluxes 2006 & 2007

Methane emission during thawing

CH₄ deposition [µg CH₄ m⁻² h⁻¹]

Spruce control
Selective cutting
Clearcut
Average yearly N$_2$O emissions

[kg N$_2$O-N ha$^{-1}$ a$^{-1}$]

- **control**
- **selective cutting**
- **clearcut**

**N$_2$O fluxes: annual means**

- **Jan-Sep**
- **Jul-Dec**

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan-Sep</th>
<th>Jul-Dec</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
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<td>0.0</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
<td>0.0</td>
<td>1.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
CH$_4$ fluxes: annual means

Average yearly CH$_4$ flux [kg CH$_4$-C ha$^{-1}$ a$^{-1}$]

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan-Sep</th>
<th>Jul-Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>-2.5</td>
<td>-1.5</td>
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<tr>
<td>2000</td>
<td>-2.0</td>
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</tr>
<tr>
<td>2001</td>
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<td>-1.0</td>
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<td>2006</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>2007</td>
<td>1.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

- control
- selective cutting
- clearcut
Soil CO$_2$ fluxes

CO$_2$ emission [mg C m$^{-2}$ h$^{-1}$]

- Control
- Selective cutting
- Clearcut

Jan Mrz Mai Jul Sep Nov Jan Mrz Mai Jul Sep Nov Jan
2000 2001

NitroEurope Open Science Conference Gent, February 20-21, 2008
Bacterial biomass C and N

1999-2005 (n = 25, fumigation-extraction)

Bacterial biomass C
- Control
- Selective cutting
- Clearcut

Biomass N
- Control
- Selective cutting
- Clearcut

Organic layer vs. $A_h$ horizon
Functional groups of microbes involved in N turnover

Aerobic heterotrophic bacteria

Chemoautotrophic nitrite oxidizers

Denitrifying bacteria

Aerobic heterotrophic nitrifiers

% of Colony Forming Units (CFU) of control

% of CFU of control
Calculated greenhouse gas budgets of forest conversion over a period of 80 years

**CO₂**

- NEE [kg CO₂-C ha⁻¹ a⁻¹]
- Clearcut
- Selective cutting

**N₂O**

- N₂O emission [kg CO₂-C equiv. ha⁻¹ a⁻¹]
- Clearcut
- Selective cutting

**CH₄**

- CH₄ flux [kg CO₂-C equiv. ha⁻¹ a⁻¹]
- Clearcut
- Selective cutting

**Sum of CO₂, N₂O and CH₄**

- Total greenhouse gas exchange [kg CO₂-C equiv. ha⁻¹ a⁻¹]
- Clearcut
- Selective cutting

Papen & Brüggemann, 2006
Calculated total greenhouse gas budget of forest conversion over a period of 80 years

CO₂-C equivalents in 80 years

[t CO₂-C equivalents ha⁻¹]

-80 -60 -40 -20 0 20 40

CO₂ N₂O CH₄ Total

Clearcut
Selective cutting

-35 % -24 %

Papen & Brüggemann, 2006
Conclusions

In contrast to selective cutting, clearcut led to

- a strong increase of nitrate leaching for 2 years,
- an enormous increase of soil $N_2O$ emissions for 4 years,
- a strong decrease in $CH_4$ uptake for at least 8 years,
- an offset of the total greenhouse gas budget of the forest of 9% more than selective cutting over the course of 80 yrs,

in an N-saturated spruce forest ecosystem in Central Europe.