RESULTS
Chapter IV

RESULTS

Methane Emission from Natural Wetland containing Peat Soil

Physicochemical characteristics of soil at Lake Khajjiar in 2005

The soil collected from the Lake Khajjiar was analysed for few basic parameters. The soil at Site-1 and 3 had circumneutral pH whereas at Site-2, the soil was relatively acidic (Table 2). The conductivity (mS) of soil was low at Site 2 compared to the other two sites (Table 2).

Table 2 The variation in pH and conductivity in soils at the three sites of Lake Khajjiar in 2005

<table>
<thead>
<tr>
<th>Sites</th>
<th>pH</th>
<th>Conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Site 1</td>
<td>7.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Site 2</td>
<td>6.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Site 3</td>
<td>7.1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Site-1 (Fig.5) showed a higher content of organic matter (%), Readily Mineralizable Carbon (RMC) and microbial biomass carbon across all three layers of soil core compared to the other two sites. The mean organic matter content was 63.61±9.22% at Site-1, 60.68±1.32% at Site-2 and 53.44±6.42 % at Site -3. At Site-1, the highest organic matter content was 70.75% from 0-5 cm core followed by 66.89% from 15-25 cm core and the minimum was 53.20% from the 5-15 cm core. At Site-2, the highest organic matter content was 64.59% from the 0-5cm, followed by 62.20 % and 59.97 % from 5-15 cm and 15-25 cm cores. At Site-3 the highest organic matter content was 60.70% from 0-5cm layer, followed by 59.69% in the 5-15cm and then 53.76% in 15-25cm layer. The RMC and microbial biomass content was highest at Site-1, followed by Site-2 and 3. The 0-5cm layer in each site showed higher RMC and microbial biomass carbon content. The Spearmann’s nonparametric correlation between % organic matter content and RMC is 0.619 and between % organic matter content and microbial biomass carbon is also 0.619.
Fig. 5 Variation of Readily Mineralizable Carbon (RMC) (µg g⁻¹), Microbial biomass carbon (µg g⁻¹) and organic matter (%) in different depths and sites in Khajjiar Lake in 2005.

**Methane Emission from dominant vegetation at Lake Khajjiar**

Methane emission varied between the vegetated and unvegetated sediment, between different types of vegetation and also between the three sites (Fig. 6).

Fig. 6 The variation in the average rate of methane emission (mg m⁻² hr⁻¹) from unvegetated and vegetated soil at three different sites at Lake Khajjiar.
At Site-1 (Fig. 6), the bare soil emitted higher methane at rate of $0.37 \pm 0.21 \text{ mg m}^{-2} \text{ hr}^{-1}$. Significant variation was not found between the three replicates of soil ($F$-value$=2.03$, $F$ critical$=5.14$, $p$-value$=0.212$, df=8) and also between the flux on three days ($F$-values$=0.658$, $F$-critical values$=5.14$, $p$-value$=0.55$, df=8). The dominant plant species present in the site were *Phragmites* and *Acorus*. The rate of methane emission was $0.32 \pm 0.058 \text{ mg m}^{-2} \text{ hr}^{-1}$ from *Acorus* and $0.18 \pm 0.025 \text{ mg m}^{-2} \text{ hr}^{-1}$ from *Phragmites* sp. Significant variation in the rate of methane emission was not seen between the three replicates ($F$-value$=4.495$, $F$-critical value$=5.14$, $p$=0.05, df=8) and also between the emission over three days ($F$-value$=0.67$, $F$-critical value$=5.143$, $p$-value$=0.54$, df=8) from *Acorus* sp.

At Site-2 (Fig. 6), the rate of methane emission from bare soil was $(0.30 \pm 0.11 \text{ mg m}^{-2} \text{ hr}^{-1})$ higher than the vegetated soil. No significant variation was observed in the rate of methane emission between the soil replicates ($F$-value$=1.33$, $F$-critical value$=5.14$, $p$-value$=0.33$, df=8) and the flux over three days ($F$-value$=1.01$, $F$-critical value$=5.14$, $p$-value$=0.42$, df=8). Between the dominant plants present at this site the methane emission was higher from *Acorus* sp. $(0.14 \pm 0.012 \text{ mg m}^{-2} \text{ hr}^{-1})$ than *Cyperus* sp. $(0.07 \pm 0.01)$. Significant variation in the rate of methane emission was not observed between the three replicates of *Acorus* sp. ($F$-value$=0.36$, $F$-critical value$=5.14$, $p$-value$=0.71$, df=8) and *Cyperus* sp. ($F$-value$=0.11$, $F$-critical value$=5.14$, $p$-value$=0.89$, df=8) but a significant variation was observed between the emissions over the three days in both the species (*Acorus* sp.- $F$-value$=19.01$, $F$-critical value$=10.92$, $p$-value$=0.0025$, df=8; *Cyperus* sp.-$F$-value$=. 56.94$, $F$-critical value$=5.14$, $p$-value$=0.0001$, df=8).

At Site-3 (Fig. 6), the vegetated soil showed higher rate of methane emission than the bare soil. The rate of methane emission from the dominant plant *Phragmites* sp. was $1.33 \pm 0.93 \text{ mg m}^{-2} \text{ hr}^{-1}$ and bare soil was $0.37 \pm 0.33 \text{ mg m}^{-2} \text{ hr}^{-1}$. There was no significant variation in rate of methane emission from the replicates of *Phragmites* sp ($F$-value$=4.7$, $F$-critical value$=5.14$, $p$-value$=0.059$, df=8) and also between the emission over the three days ($F$-value$=0.76$, $F$-critical value$=5.14$, $p$-value$=0.51$, df=8). The emission of methane from bare soil did not differ significantly between the replicates ($F$-value$=0.88$, $F$-critical value$=5.14$, $p$-value$=0.46$, df=8) and also over the three days ($F$-value$=0.79$, $F$-critical value$=5.14$, $p$-value$=0.49$, df=8).
Inter-site variability in the rate of methane emission was not significantly different in soils (F-value=0.10, F-critical value=6.94, P-value=0.90, df=8 for rate of emission between three days at Site 1, 2 and 3; F-value=0.76, F-critical value=6.94, P-value=0.51, df=8 for rate of emission between soils at Site 1, 2 and 3 on each day). In plants, the maximum rate of methane emission was observed in Phragmites sp at Site 3 followed by Acorus sp in both the sites and the lowest rate was from Cyperus sp. A significant variation was observed between rates of emission from Acorus sp. at Site 1 and Site 2 (F-value=18, F-critical value=7.70, P-value=0.012, df=5). A significant variation was also observed between rates of emission from Phragmites sp at Site 1 and Site 3 (F-value=7.74, F-critical value=7.70, P-value=0.049, df=5).

Ebullition or a very high rate of emission was observed from soil at a rate 17 mg m\(^{-2}\) hr\(^{-1}\) at Site 1 and 343 mg m\(^{-2}\) hr\(^{-1}\) at Site 2.

**Methane Emission and Plant biomass**

The number of plants present during sampling and their corresponding biomass volume (cm\(^3\)), total leaf length (cm) and dry weight (g) are presented below.

**Site-1**

At Site-1 (Table 3), Phragmites plants were young and few in numbers compared to the Acorus plants. The plants in the first day were bit damaged while sampling, so the number of plants sampled in the first day varied from 2\(^{nd}\) and 3\(^{rd}\) day.

Table 3. The characteristics of the plants sampled from Site-1 at Lake Khaijiar.

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Phragmites</th>
<th>Acorus I</th>
<th>Acorus II</th>
<th>Acorus III</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of Plants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Biomass Volume (cm(^3))</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>14.27</td>
<td>54.13</td>
<td>135.07</td>
<td>54.76</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>15.69</td>
<td>71.29</td>
<td>181.59</td>
<td>105.41</td>
</tr>
<tr>
<td><strong>Total Leaf Length (cm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>171</td>
<td>536</td>
<td>918</td>
<td>668.5</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>155.5</td>
<td>617</td>
<td>1137.5</td>
<td>778</td>
</tr>
<tr>
<td><strong>Dry Weight (g)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>2.17</td>
<td>5.84</td>
<td>14.06</td>
<td>8.69</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>2.38</td>
<td>7.58</td>
<td>18.77</td>
<td>11.05</td>
</tr>
</tbody>
</table>
The regression equation and the \( r^2 \) value of the correlation between rate of methane emission (mg m\(^{-2}\) hr\(^{-1}\)) and biomass (gDW m\(^{-2}\)) of plants at Site-1 are given below (Fig. 7).

Acorus 1: \( y = 0.0086x - 0.3693 \), \( r^2 = 0.9776 \),
Acorus 2: \( y = 0.0011x + 0.1299 \), \( r^2 = 0.8039 \),
Acorus 3: \( y = 0.001x + 0.0916 \), \( r^2 = 0.2474 \),
Phragmites sp.: \( y = -0.0151x + 0.6045 \), \( r^2 = 0.7206 \)

Fig. 7 Variation in methane emission (mg m\(^{-2}\) hr\(^{-1}\)) from vegetations in relation to plant biomass (gDW m\(^{-2}\)) at Site-1.

The regression equation and the \( r^2 \) value of the correlation between rate of methane emission (mg m\(^{-2}\) hr\(^{-1}\)) and total shoot length (cm) of plants at Site-1 are given below (Fig. 8).

Acorus 1: \( y = 0.0002x - 0.9964 \), \( r^2 = 0.9807 \)
Acorus 2: \( y = 2E-05x + 0.0492 \), \( r^2 = 0.8039 \)
Acorus 3: \( y = 3E-05x - 0.0279 \), \( r^2 = 0.2543 \)
Phragmites sp. \( y = -0.0002x + 0.6045 \), \( r^2 = 0.7206 \)
Results

Fig. 8 Variation in methane emission (mg m\(^{-2}\) hr\(^{-1}\)) from vegetations in relation to total shoot length (cm m\(^{-2}\)) in Site-1.

At Site-1, the rate of methane production did not change with an increase in the biomass (Fig. 7) and total shoot length (Fig. 8) of *Phragmites* sp., but it did increase in case of *Acorus* sp.

Site-2

The *Cyperus* plants (Table 4) have single culms and so there was variation in the shoot numbers between the sampling days and in *Acorus* sp. the vegetation was dense and so the shoots varied in the chambers in the first two days.

Table 4. The characteristics of the plants sampled from Site-2 at Lake Khajjiar.

<table>
<thead>
<tr>
<th>Site-2</th>
<th>Cyperus-I</th>
<th>Cyperus-II</th>
<th>Cyperus-III</th>
<th>Acorus-I</th>
<th>Acorus-II</th>
<th>Acorus-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>16</td>
<td>23</td>
<td>16</td>
<td>3</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>14</td>
<td>21</td>
<td>16</td>
<td>4</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>Biomass Volume (cm(^3))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>67.64</td>
<td>75.32</td>
<td>63.88</td>
<td>128.29</td>
<td>161.77</td>
<td>288.91</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>55.81</td>
<td>62.18</td>
<td>60.92</td>
<td>134.44</td>
<td>208.50</td>
<td>300.36</td>
</tr>
<tr>
<td>Total Leaf Length (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>855</td>
<td>952</td>
<td>807.5</td>
<td>886</td>
<td>1044</td>
<td>1644</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>705.5</td>
<td>786</td>
<td>770</td>
<td>915</td>
<td>1264.5</td>
<td>1698</td>
</tr>
<tr>
<td>Dry Weight (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td>6.21</td>
<td>6.92</td>
<td>5.87</td>
<td>6.44</td>
<td>16.76</td>
<td>29.66</td>
</tr>
<tr>
<td>Day 2 &amp; 3</td>
<td>5.12</td>
<td>5.71</td>
<td>5.59</td>
<td>13.99</td>
<td>21.50</td>
<td>30.82</td>
</tr>
</tbody>
</table>
The regression equation and the $r^2$ value of the correlation between rate of methane emission (mg m$^{-2}$ hr$^{-1}$) and biomass (g DW m$^{-2}$) of plants at Site -2 are given below (Fig.9).

Cyperus 1: $y = -0.0002x + 0.0439$, $r^2 = 0.0142$
Cyperus 2: $y = 0.0014x + 0.0304$, $r^2 = 0.353$
Cyperus 3: $y = -0.0006x + 0.0747$, $r^2 = 0.0478$
Acorus 1: $y = 0.0002x + 0.0287$, $r^2 = 0.3332$
Acorus 2: $y = 0.0011x - 0.0935$, $r^2 = 0.9766$
Acorus 3: $y = 0.0047x - 1.5749$, $r^2 = 0.9948$

![Graph showing variation in methane emission in relation to plant biomass at Site-2.](image)

**Fig.9** Variation in methane emission (mg m$^{-2}$ hr$^{-1}$) from vegetations in relation to plant biomass (gDW m$^{-2}$) in Site-2.

The regression equation and the $R^2$ value of the correlation between rate of methane emission (mg m$^{-2}$ hr$^{-1}$) and total shoot length (cm) of plants at Site-2 are given below (Fig.10).

Cyperus 1: $y = -2E-05x + 0.0439x$, $r^2 = 0.0142$
Cyperus 2: $y = 0.0001x + 0.0304$, $r^2 = 0.353$
Cyperus 3: $y = -5E-05x + 0.0747$, $r^2 = 0.0478$
Acorus 1: $y = 0.0005x - 0.4096$, $r^2 = 0.332$
Acorus 2: $y = 0.0003x - 0.1755$, $r^2 = 0.9766$
Acorus 3: $y = 0.0013x - 1.912$, $r^2 = 0.9947$
Fig. 10 Variation in methane emission (mg m$^{-2}$ hr$^{-1}$) from vegetations in relation to total shoot length (cm$^2$) at Site-2.

At Site-2, the rate of methane emission increased with the increase in total biomass (g DW m$^2$) (Fig. 9) and total shoot length (cm$^2$) (Fig. 10).

Site-3

At Site-3 (Table 5), the plants and the sampling points were disturbed due to sampling and so the number of plants sampled in the last day varied.

Table 5: The characteristics of the plants that were sampled from Site-2 at Lake Khajjiar.

<table>
<thead>
<tr>
<th>Site-3</th>
<th>Phragmites-I</th>
<th>Phragmites-II</th>
<th>Phragmites-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Plants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days 1 &amp; 2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Day 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Biomass Volume (cm$^3$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days 1 &amp; 2</td>
<td>15.23</td>
<td>18.53</td>
<td>15.05</td>
</tr>
<tr>
<td>Day 3</td>
<td>12.39</td>
<td>16.51</td>
<td>14.13</td>
</tr>
<tr>
<td>Total Leaf Length (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days 1 &amp; 2</td>
<td>166</td>
<td>202</td>
<td>164</td>
</tr>
<tr>
<td>Day 3</td>
<td>135</td>
<td>180</td>
<td>154</td>
</tr>
<tr>
<td>Dry Weight (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days 1 &amp; 2</td>
<td>2.31</td>
<td>2.82</td>
<td>2.29</td>
</tr>
<tr>
<td>Day 3</td>
<td>1.88</td>
<td>2.51</td>
<td>2.15</td>
</tr>
</tbody>
</table>

Results
The regression equation and the $r^2$ value of the correlation between rate of methane emission (mg m$^{-2}$ hr$^{-1}$) and biomass (gDW m$^{-2}$) of plants at Site-3 are given below (Fig. 11).

**Phragmites 1**: $y = 0.0577x - 0.4752$, $r^2 = 0.1107$

**Phragmites 2**: $y = 0.5121x - 15.33$, $r^2 = 0.8294$

**Phragmites 3**: $y = 0.9225x - 23.694$, $r^2 = 0.9944$

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**Variation in methane emission in relation to plant biomass at Site-3**

![Graph](image)

Fig. 11 Variation in methane emission (mg m$^{-2}$ hr$^{-1}$) from vegetations in relation to plant biomass (gDW m$^{-2}$) at Site-3.

The regression equation and the $r^2$ value of the correlation between rate of methane emission (mg m$^{-2}$ hr$^{-1}$) and total shoot length (cm) of plants at Site-3 are given below (Fig. 12).

**Phragmites 1**: $y = 0.008x - 0.4752$, $r^2 = 0.1107$

**Phragmites 2**: $y = 0.0071x - 15.33$, $r^2 = 0.8299$

**Phragmites 3**: $y = 0.0129x - 23.694$, $r^2 = 0.9944$
Fig. 12 Variation in methane emission (mg m\(^{-2}\) hr\(^{-1}\)) from vegetations in relation to plant shoots (cm m\(^{-2}\)) at Site-3.

At Site-3 (Fig. 11) the rate of methane emission changed with or without the change in plant biomass (gDW m\(^{-2}\)) and total shoot length (Fig. 12).

**Methane Emission from Natural Wetland containing Mineral Soil**

Experiments were conducted to investigate the role of plant in methane emission when grown in mineral soils. *Scirpus* plants were grown in soils of different types in tanks in the garden of School of Environmental Sciences.

**Physicochemical factors of Soil**

Texture analysis of soil (Table 6.) done at the end of the experiment showed that sand content of the Sandy soil was highest followed by Bhalswa soil and then Garden soil. The clay content of the Bhalswa soil was highest followed by Garden soil and then Sandy soil. The silt content of Garden soil was highest followed by Bhalswa soil and then Sandy soil.
Table 6. Texture analysis of soils used for growing Scirpus plants.

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Sand %</th>
<th>Clay %</th>
<th>Silt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy soil</td>
<td>67.91 ± 3.93</td>
<td>14.84 ± 0.44</td>
<td>19.75 ± 3.31</td>
</tr>
<tr>
<td>Bhalswa soil</td>
<td>45.03 ± 0.14</td>
<td>31.31 ± 0.66</td>
<td>23.67 ± 0.52</td>
</tr>
<tr>
<td>Garden soil</td>
<td>46.64 ± 1.97</td>
<td>20.2 ± 4.96</td>
<td>32.35 ± 3.87</td>
</tr>
</tbody>
</table>

The organic carbon determined by Walkley-Black method determines the partially oxidisable organic carbon of soil. The organic carbon content varied significantly across all soil types (F-value=10.77, F-critical value=4.25, p-value=0.004, df=11) but not over the four months (F-value=0.61, F-critical value=4.06, p-value=0.63, df=11) (Fig.13). It was high in Garden soil compared to Bhalswa and Sandy soil. The variation of organic carbon content over the four months was more pronounced in the Garden soil.

![Variation in Organic Carbon (%) in different soils in different months](image)

Fig.13 The variation in organic carbon content (%) of Bhalswa, Sandy and Garden soil over a period of four months.

Total organic matter was analysed for the month of July by Loss on ignition method (Heiri et al, 2001) and total nitrogen by colorimetric method. The total organic matter and C/N ratio was higher in Bhalswa soil, followed by Garden soil and Sandy soil (Table.7). The C/N ratio of Bhalswa soil was higher than Garden and Sandy soil.
Table 7. The variation in organic carbon (%), Total organic matter (%) and C/N ratio in three soil types in July.

<table>
<thead>
<tr>
<th>Soil Types</th>
<th>Organic Carbon (%)</th>
<th>Total organic matter (%)</th>
<th>Total Nitrogen (%)</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhalswa Soil</td>
<td>0.48±0.01</td>
<td>7.53±0.05</td>
<td>0.17</td>
<td>2.82</td>
</tr>
<tr>
<td>Sandy Soil</td>
<td>0.065±0.01</td>
<td>2.25±0.38</td>
<td>0.27</td>
<td>0.24</td>
</tr>
<tr>
<td>Garden Soil</td>
<td>0.19±0.01</td>
<td>4.56±0.39</td>
<td>0.22</td>
<td>0.85</td>
</tr>
</tbody>
</table>

*Methane emission from vegetated and bare soil of Bhalswa Lake*

Methane emission from vegetated and bare soil of Bhalswa Lake was sampled in four different months. On 17th May, the samples were collected every half an hour for two hours. This sampling for two hour was repeated four times (4:00-6:00 hr, 12:00-14:00 hr, 14:00-16:00 hr and 20:00-22:00 hr) during the day. On 9 and 10th June, the frequency of sampling was increased to six times wherein the samples were collected for two hour from 4:00-6:00 hr, 7:00-9:00 hr, 11:00-13:00 hr, 14:00-16:00 hr, and 20:00-22:00 hr on the first day and from 16:00-18:00 hr in the consecutive day. On 2nd July and 5th October, sampling was done for three times covering day and night-4:00-6:30 hr, 12:00-14:00 hr and 20:00-22:00 hr.
Results

b) June

![Graph showing rate (mg m^-2 hr^-1) versus time (hr) for June. The graph compares Bhalswa Soil and Bhalswa Soil + Scirpus sp.]

June

Rate (mg m^-2 hr^-1)

Time (hr)

-4 -2 0 2 4 6 8 10 12 14 16

Bhalswa Soil
Bhalswa Soil + Scirpus sp.

![Graph showing rate (mg m^-2 hr^-1) versus time (hr) for July. The graph compares Bhalswa Soil and Bhalswa Soil + Scirpus sp.]

July

Rate (mg m^-2 hr^-1)

Time (hr)

-4 -2 0 2 4 6 8 10 12 14 16

Bhalswa Soil
Bhalswa Soil + Scirpus sp.

c)
d) 

Fig.14. Variation in rate of methane emission (mg m$^{-2}$ hr$^{-1}$) for every half an hour interval, from bare and vegetated Bhalswa soil a) on 17th May 2006, b) 9th and 10th June 2006, c) 2nd July 2006 and d) 5th October 2006

The result of the methane sampling was the following:-

1) The rate of methane emission from vegetated soil was always higher than the bare soil

2) The peak emission was always after sunrise and as the time of sunrise shifted from month to month, the timing of the peak rate of emission shifted over the months.

On 17th May (Fig.14a), the rate of methane emission fluctuated more in vegetated sediments and was higher (ranged from 3.19±1.91 to 9.38±1.75 mg m$^{-2}$ hr$^{-1}$) than the unvegetated sediment (ranged from -1.11 to 2.25 mg m$^{-2}$ hr$^{-1}$) of Bhalswa soil. The rate of methane emission for every half an hour did not vary but a distinct peak between 5:30-6:00 hr at a rate of 9.38±1.75 mg m$^{-2}$ hr$^{-1}$ was observed in the early morning after sunrise. The rate of methane emission showed a common trend of increase for every half an hour within the two hours. In the noon and afternoon from 12:00 to 14:00 hr and 14:00 to 16:00 hr a stable rate of methane emission was observed. The rate of methane emission at night from 20:00 to 22:00 hr, increased from 4.09±2.38 to 6.37±4.29 mg m$^{-2}$ hr$^{-1}$. The rate of methane emission ranged from 0.49 to 0.76 mg m$^{-2}$ hr$^{-1}$ between 4:00-6:30 hr, -1.11 to 5.00 mg m$^{-2}$ hr$^{-1}$ between
14:00-16:00 hr and -0.76 to 0.65 mg m\(^{-2}\) hr\(^{-1}\) between 20:00-22:00 hr. The sudden rise in the rate of emission from bare soil at 15:30 hr at a rate of 5.00 mg m\(^{-2}\) hr\(^{-1}\) may be due to ebullition.

On 9th and 10th June (Fig.14b), the frequency of sampling was increased. The rate of methane emission varied significantly in every two hours over the six sampling time points (F-value=7.35, F-critical value=3.33, P value=0.004, df=17). The rate of emission varied from 2.32±0.832 to 11.53±3.547 mg m\(^{-2}\) hr\(^{-1}\) in the vegetated sediment. In the vegetated sediment the highest peak (11.53 ±3.547 mg m\(^{-2}\) hr\(^{-1}\)) was observed between 5:00-5:30 hr. The rate of emission dipped at 10:00-12:00 hr (from 4.50±2.60 to 2.85±0.85 mg m\(^{-2}\) hr\(^{-1}\)) and 16:00-18:00 hr (from 5.01±2.57 to 2.79±0.88 mg m\(^{-2}\) hr\(^{-1}\)). The rate of emission increased at night from 20:00-22:00 hr increased from 2.50±1.87 to 7.23±4.86 mg m\(^{-2}\) hr\(^{-1}\) till 21:30 hr and then declined in the last half an hour to 6.46±2.35 mg m\(^{-2}\) hr\(^{-1}\). The rate of emission recorded last at 22:00 hr was close to the rate of emission (5.86±2.14 mg m\(^{-2}\) hr\(^{-1}\)) seen in the dark hours before dawn (4:00-5:00 hr). The rate of emission from bare soil was low and consistent over different time of day and night. The rate of methane emission varied from the unvegetated soil ranged from 0.10 to 0.71 mg m\(^{-2}\) hr\(^{-1}\) between 4:00-6:00 hr, -0.07 to 0.33 mg m\(^{-2}\) hr\(^{-1}\) between 7:00-9:00 hr, -1.48 to 0.24 mg m\(^{-2}\) hr\(^{-1}\) between 10:00-12:00 hr, 0.20 to 0.82 mg m\(^{-2}\) hr\(^{-1}\) between 14:00-16:00 hr, -0.09 to 0.34 mg m\(^{-2}\) hr\(^{-1}\) between 16:00-18:00 hr and 0.26-0.91 mg m\(^{-2}\) hr\(^{-1}\) between 20:00-22:00 hr.

On 2nd July (Fig.14c), the rates did not vary significantly in every half an hour over the three sampling period (F-value=5.68, F-critical value=6.94, P-value=0.068, df=2). The peak emission was distinct between 5:00-5:30 hr at a rate of 9.77±3.65 mg m\(^{-2}\) hr\(^{-1}\). The rate of emission declined to 3.08±1.61 mg m\(^{-2}\) hr\(^{-1}\) (minimum observed) between 6:00-6:30 hr after the peak emission. Between 14:00 and 16:00 hr the rate of emission increased till 15:00 hr at a rate of 5.95±0.69 to 6.69±0.75 mg m\(^{-2}\) hr\(^{-1}\), dipped at 15:30 hr at a rate of 4.47±0.92 mg m\(^{-2}\) hr\(^{-1}\) and then shot up to 8.31±3.09 mg m\(^{-2}\) hr\(^{-1}\). At night between 20:30 and 22:00 hr the rate of methane emission increased from 4.23±2.51 to 7.66±3.292 mg m\(^{-2}\) hr\(^{-1}\). In the early hours of dawn before the sunrise, the rate of emission ranged from 6.65±0.47 to 7.33±2.64 mg m\(^{-2}\) hr\(^{-1}\). In the bare soil the rate of methane emission ranged from -0.79 to 0.26 mg m\(^{-2}\) hr\(^{-1}\) between 4-6:30 hr,
-1.06 to 2.16 mg m\(^{-2}\) hr\(^{-1}\) between 14:00-16:00 hr and 0.22 to 1.05 mg m\(^{-2}\) hr\(^{-1}\) between 20:00-22:00 hr.

On 5\(^{th}\) October (Fig. 14d), the rate methane emission was sampled from *Scirpus* plants grown in two tanks only. The peak emission was distinct after sunrise between 5:30-6:00 hr at a rate of 8.94 mg m\(^{-2}\) hr\(^{-1}\). The rate of emission declined to 2.59 mg m\(^{-2}\) hr\(^{-1}\) after the peak. In the afternoon the rate of emission increased (4.94 to 6.32 mg m\(^{-2}\) hr\(^{-1}\)) every half an hour till 3:30 hr and then the rate declined to 1.57 mg m\(^{-2}\) hr\(^{-1}\). At night between 20:00 and 22:00 hr the rate increased from 5.62 to 6.27 mg m\(^{-2}\) hr\(^{-1}\) till 21:00 hr and then decreased gradually to 3.86 and 0.73 mg m\(^{-2}\) hr\(^{-1}\) (minimum peak observed) between 21:30 to 22:00 hr. In the bare soil the rate of emission varied from -0.31 to 4.33 mg m\(^{-2}\) hr\(^{-1}\). The rate in the early morning before sunrise was at 6.23 to 3.68 mg m\(^{-2}\) hr\(^{-1}\) between 4:30-5:30 hr. In the bare soil the rate of methane emission ranged from 0.13 to 0.70 mg m\(^{-2}\) hr\(^{-1}\) between 4:00-6:30 hr, 0.039 to 1.328 mg m\(^{-2}\) hr\(^{-1}\) between 14:30-16:00 hr and -0.308-4.325 mg m\(^{-2}\) hr\(^{-1}\) between 20:00-22:00 hr.

*Methane emission from vegetated and bare Sandy Soil*

In 10th and 11th May, the plants and bare soil were sampled 6 times for every half an hour between 4:00-6:30 hr, 7:00-9:00 hr, 10:00-12:00 hr, 14:00-16:00 hr, 16:00-18:00 hr and 20:00-22:00 hr to estimate the diurnal rate of emission. The sampling point of 16:00-18:00 hr was conducted in the consecutive day. On 14th June, 1st July and 10th October the sampling was done three times for every half an hour between 4:00-6:30 hr, 14:00-16:00 hr and 20:00-22:00 hr.
Results

May

- Sandy Soil
- Sandy Soil + Scirpus sp.

June

- Sandy Soil
- Sandy Soil + Scirpus sp.
Fig. 15 Variation in rate of methane emission (µg m\(^{-2}\) hr\(^{-1}\)) for every half hour an interval, from bare and vegetated Sandy soil on a) 10\(^{th}\) and 11\(^{th}\) May 2006, b) 14\(^{th}\) June 2006, c) 1\(^{st}\) July 2006 and d) on 10\(^{th}\) October 2006

The result of the methane sampling was the following:-

1) The rate of methane emission was higher from the vegetated sediment compared to the unvegetated sediment except in October when the emission from soil sometimes was more than the former.
2) The rate of emission always peaked after the sunrise. The peak shifted with the shift in time of sunrise.

3) The rate of methane emission was low (expressed in terms of \( \mu g \, m^{-2} \, hr^{-1} \)) compared to the Bhalswa and Garden soil.

On 10\(^{th}\) and 11\(^{th}\) May (Fig.15a), the rate of methane emission ranged from 2504.86 ± 622.98 to 629.00 ± 483.59 \( \mu g \, m^{-2} \, hr^{-1} \) from the vegetated sediment. Methane emission peaked at a rate of 1029.70±471.23 \( \mu g \, m^{-2} \, hr^{-1} \) in between 5:30 and 6:00 hr. The rate of emission ranged from 564.44±283.42 to 578.54±494.39 \( \mu g \, m^{-2} \, hr^{-1} \) between 7:00 and 8:00 hr, it declined to 515.72±543.81 \( \mu g \, m^{-2} \, hr^{-1} \) between 8:00 and 8:30 hr and increased to 719.83±180.66 \( \mu g \, m^{-2} \, hr^{-1} \) between 8:30 and 9:00 hr. Between 10:00 and 12:00 hr, the rate fluctuated every half hour. The rate of emission increased from 549.70±390.06 to 783.20±523.71 \( \mu g \, m^{-2} \, hr^{-1} \) until 15:00 hr and then declined to 493.64±252.45 \( \mu g \, m^{-2} \, hr^{-1} \) between 15:30 and 16:00 hr. In the evening between 16:00 and 18:00 hr, the trend of the rate of emission was similar to that in afternoon. At night too the trend was same but the rate dipped to 208.55±43.65 \( \mu g \, m^{-2} \, hr^{-1} \). The mean rate of 764.99±942.92 \( \mu g \, m^{-2} \, hr^{-1} \) (methane emission) observed at the first hour of sampling before dawn is close to the rate observed between 21:30 and 22:00 hr. The rate of emission did not vary significantly for every half an hour for the six time points (F-value=0.55, F-critical value=2.99, P-value=0.76, df=14). The rate of methane emission in the unvegetated sediment ranged from 367-1169.67 \( \mu g \, m^{-2} \, hr^{-1} \).

On 14\(^{th}\) June (Fig.15b), the rate of methane emission ranged from 629±483.59 \( \mu g \, m^{-2} \, hr^{-1} \) to 2504±622.98 \( \mu g \, m^{-2} \, hr^{-1} \). The peak rate of emission was 2504±622.98 \( \mu g \, m^{-2} \, hr^{-1} \) between 5:30 and 6:00 hr. In the afternoon (14:00-16:00 hr), the rate of methane emission increased from 1452±1018.54 \( \mu g \, m^{-2} \, hr^{-1} \) to 2095.73±460.21 \( \mu g \, m^{-2} \, hr^{-1} \) in the first one hour and then decreased slightly to 1746.11±496.42 \( \mu g \, m^{-2} \, hr^{-1} \) to increase again to 1804.29±290.51 \( \mu g \, m^{-2} \, hr^{-1} \) in the next one hour. At night, the rate fluctuated between 1053.0±974.21 to 1478.49±226.27 \( \mu g \, m^{-2} \, hr^{-1} \). The rate observed between 21:30 and 22:00 hr was higher than the rate of emission (629±483.59 \( \mu g \, m^{-2} \, hr^{-1} \)) observed first in the early dawn before sunrise. But the rate of emission did increase to 1740±26.54 and 2199.10±58.20 \( \mu g \, m^{-2} \, hr^{-1} \) in the next one hour before the final peak after sunrise.
The rate of emission in the unvegetated sediment ranged from \(511-1169.67 \mu g \, m^{-2} \, hr^{-1}\). The sudden increase to \(1169 \mu g \, m^{-2} \, hr^{-1}\) between 21:30 and 22:00 hr from bare soil may be due to ebullition.

On 1\textsuperscript{st} July (Fig.15c), in the vegetated sediment, the rate of methane emission ranged from \(1852\pm295.51 \mu g \, m^{-2} \, hr^{-1}\) to \(978.82\pm559.43 \mu g \, m^{-2} \, hr^{-1}\). The peak rate of emission was between 5:30 and 6:00 hr and then the rate declined to \(1432.43\pm156.87 \mu g \, m^{-2} \, hr^{-1}\) in the next half an hour. In afternoon, the rate of methane emission fluctuated from \(1093.95\pm1379.27 \mu g \, m^{-2} \, hr^{-1}\) to \(978.82\pm559.43 \mu g \, m^{-2} \, hr^{-1}\) in the first one hour. The rate then increased to \(1931.88\pm371.53 \mu g \, m^{-2} \, hr^{-1}\) within an hour. At night the rate of emission declined from \(1864.00\pm1379.00 \mu g \, m^{-2} \, hr^{-1}\) to \(1386.89\pm422.82 \mu g \, m^{-2} \, hr^{-1}\) between 20:30 and 21:00 hr. The rate found at the early hour increased from \(1093.80\pm16.82 \mu g \, m^{-2} \, hr^{-1}\) to \(1679.09\pm1432.98 \mu g \, m^{-2} \, hr^{-1}\) before shooting to the peak rate of methane emission. In the unvegetated sediment the rate of methane emission ranged from \(4.13 \mu g \, m^{-2} \, hr^{-1}\) to \(933.74 \mu g \, m^{-2} \, hr^{-1}\). The rate of methane emission fluctuated highly from 4:00-6:30 hr in the unvegetated sediment. On average, the rate of methane emission for every half an hour did not vary for the other two sampling points.

On 10\textsuperscript{th} October (Fig.15d), the rate of emission was very low. In the vegetated sediment it ranged from \(34.527\pm10.52 \mu g \, m^{-2} \, hr^{-1}\) to \(285.43\pm240.35 \mu g \, m^{-2} \, hr^{-1}\). A small peak (\(285.43\pm214.76 \mu g \, m^{-2} \, hr^{-1}\)) was observed between 6:00 and 6:30 hr. In the afternoon the rate fluctuated from \(177.74\pm61.64 \mu g \, m^{-2} \, hr^{-1}\) to \(91.24\pm81.20 \mu g \, m^{-2} \, hr^{-1}\) within one and a half hour and then the rate increased to \(272.109\pm189 \mu g \, m^{-2} \, hr^{-1}\) in the last half hour. At night from 20:30 to 22:00 hr the rate fluctuated between \(305.40\pm100.64 \mu g \, m^{-2} \, hr^{-1}\) and \(270.82\pm80.15 \mu g \, m^{-2} \, hr^{-1}\). The rate of emission ranged from \(173.96\pm42.49 \mu g \, m^{-2} \, hr^{-1}\) to \(34.53\pm9.69 \mu g \, m^{-2} \, hr^{-1}\) before the peak rate of emission after sunrise. The rate of emission in the unvegetated sediment ranged from \(-92.32\) to \(222.69 \mu g \, m^{-2} \, hr^{-1}\). In the afternoon the rate of methane emission was higher from the vegetated than the bare soil except in the last half an hour when the rate of emission from the vegetated sediment shot up. The rate of methane emission declined steeply to \(-92.32 \mu g \, m^{-2} \, hr^{-1}\) at night.
Methane Emission from vegetated and bare Garden Soil

The plants grown on garden soil were sampled along with unvegetated garden soil. On 5th and 6th June, the sampling was conducted six times over two consecutive days. The samples were collected every half an hour from 4:00-6:00 hr, 7:00-9:00 hr, 10:00-12:00 hr, 14:00-16:00 hr, 16:00-18:00 hr and 20:00-22:00 hr. On 7th July and 10th October, the time points of sampling were 4:00-6:00 hr, 14:00-16:00 hr and 20:00-22:00 hr. The highest peak of rate of emission was observed to be always after sunrise.

![Graph a) June](image1)

![Graph b) July](image2)
On 5th and 6th June (Fig.16a), in the vegetated Garden soil, the rate of methane emission ranged from 285.42±214.76 to 34.53±4.69 mg m\(^{-2}\) hr\(^{-1}\). The peak rate of methane emission 34.53±4.69 mg m\(^{-2}\) hr\(^{-1}\) was observed between 5:00 and 5:30 hr after sunrise. In the morning between 7:00 and 9:00 hr, the rate increased from 15.79±0.65 to 16.80±1.02 mg m\(^{-2}\) hr\(^{-1}\). In noon from 10:00-12:00 hr the rate fluctuated between 18.75±3.67 and 16.56±6.20 mg m\(^{-2}\) hr\(^{-1}\). In the afternoon from 14:00-16:00 hr, the rate increased from 15.94±3.0 to 20.09±4.06 in the first hour and decreased to 13.63±4.92 mg m\(^{-2}\) hr\(^{-1}\) to again increase to 24.55±3.61 mg m\(^{-2}\) hr\(^{-1}\). In the evening, from 16:00-18:00 hr, the rate increased steadily from 7.18±3.41 to 25.22±10.09 mg m\(^{-2}\) hr\(^{-1}\) and then decreased to 18.35±1.97 mg m\(^{-2}\) hr\(^{-1}\) in the last half hour. At night between 20:00 and 21:30 hr, the rate of methane emission increased from 18.44±2.33 to 21.59±5.64 mg m\(^{-2}\) hr\(^{-1}\) and then declined to 14.20±8.72 mg m\(^{-2}\) hr\(^{-1}\). The rate observed between 20:30 and 21:00 hr (14.09±9.67 mg m\(^{-2}\) hr\(^{-1}\)) was close to the rate in the first hour 4:30 and 5:00 hr (16.09±4.05 mg m\(^{-2}\) hr\(^{-1}\)) in the morning before the peak rate of emission. In the unvegetated sediment the rate of emission ranged from –1.09 to 45.95 mg m\(^{-2}\) hr\(^{-1}\). The rate was stable between 4:00-6:00 hr, 7:00-9:00 hr and 20:00-22:00. The high rate of methane emission that was observed between 10:00 and
10:30 hr (45.95 mg m⁻² hr⁻¹) could be due to ebullition. In the afternoon from 14:00-16:00 and 16:00-18:00 hr the rate of emission from bare soil was found to be higher than from the vegetated soil.

On 1st July (Fig.16b), the rate of methane emission ranged from 3.44±0.49 to 26.22±2.27 mg m⁻² hr⁻¹ in the vegetated sediment. The peak was observed between 5:30-6:00 hr after sunrise. In the afternoon, from 14:00-16:00 hr, the rate increased gradually from 3.44±0.49 to 20.99±2.08 mg m⁻² hr⁻¹ and then decreased to 10.44±2.33 mg m⁻² hr⁻¹ in the last half an hour. At night, the rate increased gradually from 3.44±0.49 to 24.20±3.80 mg m⁻² hr⁻¹ till 22:00 hr. In the early dawn (from 4:00-5:00 hr) before sunrise, the rate of methane emission ranged between 14.92±1.2 to 15.66±4.02 mg m⁻² hr⁻¹.

The rate of methane emission from the unvegetated sediment ranged from 4.05 to 35.10 mg m⁻² hr⁻¹. The rate of emission from bare soil shoots up to 35.10 mg m⁻² hr⁻¹ in the afternoon. The rate of emission from bare soil is higher compared to the vegetated soil in afternoon and in the first hour of evening.

On 10th October (Fig.16c), the rate of methane emission from the vegetated sediment ranged from 2.23±0.71 to 8.10±1.67 mg m⁻² hr⁻¹. The peak rate of emission was observed between 5:30 and 6:00 hr after sunrise. The rate of emission increased from 3.26±1.09 mg m⁻² hr⁻¹ in the first hour of afternoon to 5.49±1.24 mg m⁻² hr⁻¹ between 14:30 and 15 hr and then decreased to 3.58±1.48 mg m⁻² hr⁻¹ in the last hour between 15:30-16:00 hr. At night the rate declined from 3.07±1.07 to 2.23±0.73 mg m⁻² hr⁻¹ between 20:00-21:30 hr. In the first one hour of sampling before sunrise the rate of emission ranged from 4.14±0.86 to 2.77±3.30 mg m⁻² hr⁻¹. The rate of methane emission from the unvegetated soil ranged from -17.50 -46.57 mg m⁻² hr⁻¹. The rate of emission of methane from bare soil varied with time of the day. In the early morning from 4:00-4:30 hr there was an ebullition of 45.67 mg m⁻² hr⁻¹. In the afternoon the rate of emission was high 23.38 mg m⁻² hr⁻¹ in the first half an hour between 14-14:30 hr and then dipped to -5.59 mg m⁻² hr⁻¹ in the next half an hour between 14:30-15:00 hr. The rate again increased to 8.69 mg m⁻² hr⁻¹ and dipped to -17.50 mg m⁻² hr⁻¹. At night the rate of methane emission was stable around 6.00 mg m⁻² hr⁻¹.
**Total Methane Emission**

To calculate the total methane emission (Table 8) for a single day mean rates were calculated (from every half an hour) for every two hours observation for which the measurements were done and multiplied with the number of hours of measurement i.e two hours. For the gaps in which sampling was not done, the average rate was worked out from the last half hour rate of emission of the previous observation and the first half hour rate of emission of the next observation between two sampling time points and multiplied it with the number of in between hours. The integration of all individual mean hourly emissions led to the total emission for that day. The total methane emission from the *Scirpus* plants of Bhalswa Soil was nearly consistent except in October. The total methane emission from the Scirpus plants of Sandy soil was highest in June and reduced thereafter. The total methane emission from the *Scirpus* plants of Garden soil was highest in July and reduced thereafter. The total methane emission from unvegetated Sandy soil and Garden soil was nearly consistent over the three months but fluctuated in Bhalswa Soil.

<table>
<thead>
<tr>
<th>Months</th>
<th>Bhalswa Soil</th>
<th>Sandy Soil</th>
<th>Garden Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vegetated</td>
<td>Bare</td>
<td>Vegetated</td>
</tr>
<tr>
<td></td>
<td>Soil</td>
<td>Soil</td>
<td>Soil</td>
</tr>
<tr>
<td>Mean±SD</td>
<td>Mean±SD</td>
<td>Mean±SD</td>
<td>Mean±SD</td>
</tr>
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<td>n=3</td>
<td>(mg m⁻²)</td>
<td>(mg m⁻²)</td>
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<tr>
<td>May</td>
<td>129.07±54.11</td>
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<td>11.46±1.96</td>
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</tr>
<tr>
<td>July</td>
<td>129.09±29.87</td>
<td>43.50</td>
<td>34.49±16</td>
</tr>
<tr>
<td>October</td>
<td>93.62±9.54</td>
<td>22.51</td>
<td>5.17±1.80</td>
</tr>
</tbody>
</table>

The mean diurnal rate for every two hours was calculated from the individual half hourly rates of observation for the days on which the sampling was conducted for six times (over day and night). The mean diurnal rate of methane emission from *Scirpus* plants grown in Bhalswa Soil was highest in the morning that coincided with the time of the peak rate of emission (Fig.17).
The mean diurnal rate of methane emission from Scirpus plants grown in Sandy soil was highest in between 4:00 and 6:00 hr (0.76±0.27 38 mg m\(^{-2}\) hr\(^{-1}\)) and coincided with the highest individual peak rate of emission. The rate of methane emission from afternoon between 14:00 and 16:00 hr (0.609±0.26 38 mg m\(^{-2}\) hr\(^{-1}\)) followed next. In the morning from 7:00-9:00 hr the rate of emission was 0.59±0.18 38 mg m\(^{-2}\) hr\(^{-1}\). The rate of methane emission was least at night between 20:00 and 22:00 hr (0.39±0.19 mg m\(^{-2}\) hr\(^{-1}\)).

The mean diurnal rate of methane emission from Scirpus plants grown in garden soil was highest in between 14:00 and 16:00 hr (18.51±3.57 mg m\(^{-2}\) hr\(^{-1}\)) and did not coincide with the peak rate of emission between 5:00 and 5:30 hr. The mean rate of emission was also very high at night 18.41±5.11 mg m\(^{-2}\) hr\(^{-1}\) compared to the rate at other time of the day. It was least in the morning 7:00-9:00 hr (14.59±1.69 mg m\(^{-2}\) hr\(^{-1}\)).

Mean Diurnal Methane Emission

Fig. 17. Mean diurnal rate of methane emission from vegetated and unvegetated soil.
The comparison (Fig. 18 and 19) of the mean daily rate of methane emission from vegetated soil and unvegetated soil over four months showed that the rate of emission was higher from former than later. In May, the rate of methane emission from vegetated soil was 7.15 and 4.19 times more than in bare Bhalswa and Sandy soil respectively. In June, the rate of emission from vegetated soil was higher by 15, 2.22, 4.198 times compared to unvegetated soil in Bhalswa, Sandy and Garden soil, respectively. In October, the vegetated Bhalswa and sandy soil emitted methane at a rate about 4.15 and 2.7 times more than the unvegetated soil. As an exception in October, the overall rate of methane emission was low and the unvegetated Garden soil emitted methane at a rate of 2.45 times compared to the vegetated soil. In general, the difference in the rates between the vegetated and unvegetated soil increased from May to June, reduced in July and again increased in October except for the Garden soil.

Fig. 18. Comparison of the mean daily rate of methane emission from bare soil for over four months.
Results

Fig. 19. Comparison of the mean daily rate of methane emission from vegetated soil for over four months.

**Total Organic Carbon and Total Methane Emission**

A positive and significant correlation was observed (Fig. 20) between the organic carbon (%) and total methane emission (mg m\(^{-2}\)). The coefficient of correlation between organic carbon and total methane emission from *Scirpus* plants grown in Bhalswa, Sandy and Garden soil was 0.94, 0.73 and 0.65, respectively.

Fig. 20. Relationship between total organic carbon (%) and total methane emission (mg m\(^{-2}\))
**Plant Biomass**

Plants grown in different soils differed in its biomass (dry weight) (Fig.No.21). The biomass of the *Scirpus* plants grown in Bhalswa Soil increased from 2077.21±140.68 g m\(^{-2}\) (for 95±7 shoots) in May, 2777.10±319.55 (for 96±12 shoots) in June to 2817.54±143.40 g m\(^{-2}\) (for 113±4 shoots) in July and decreased to 1036.25 g m\(^{-2}\) (for 61 shoots) in October.

The biomass of the *Scirpus* plants grown in Sandy soil increased from 1934.64±33.52 gm\(^{-2}\) (for 105±8 shoots) in May, to 2287.0±183.69 gm\(^{-2}\) (for 98±6 shoots) in June and reduced to 1909.68±194.35 gm\(^{-2}\) (for 78±8 shoots) in July and 1036±137.88 gm\(^{-2}\) (47±4) October.

The *Scirpus* plants growing in the Garden soil showed higher biomass content compared to the other two types of soil. The dry weight of the plants reduced from 3734.57±350.37 g m\(^{-2}\) (for 140±9 shoots) in June to 3658±393.94 g m\(^{-2}\) (for 122±15 shoots) in July and further to 1593±93.91 g m\(^{-2}\) (for 61±3 shoots) in October.

![Graph](image)

**Fig.21.** The variation in the plant biomass (gDW m\(^{-2}\)) grown in Bhalswa, Sandy and Garden soil over the months.
Plant Biomass and Methane Emission

Fig. 22. Variation in daily rate of methane emission (mg m⁻² hr⁻¹) against plant biomass (g m⁻²) from a) Bhalswa, b) Sandy and c) Garden soil.

Results
Exponential trendline (order 2) was best suited to bring forth the correlation between the daily rate of methane emission and plant biomass. The coefficient of correlation between the daily rate of methane emission and plant biomass was positive in all types of soil but it was very weak in Bhalswa soil. Only 7% ($r^2=0.23$) variation in the increase in methane emission could be explained with the increase in biomass (Fig.22a). In Sandy soil 60.52% ($r^2=0.79$) (Fig.22b) of variation in the increase in methane emission was explained by the increase in biomass whereas 74.32% ($r^2=0.88$) variation in the increase in methane emission with the increase in biomass of plants in Garden soil (Fig.22c) could be explained.

**Influence of water level on methane emission**

*Scirpus* plants grown in garden soils were subjected to two different water levels of 15 cm (2 tanks) and 30 cm (2 tanks) after a prolonged period of dryness (~15 days) (Fig. 23). The other two tanks with the plants had water level 1-2 cm below surface. The rate of emission of methane was investigated thereafter at the end of June and first week of July.

The rate of emission differed with water level (Fig. 23). The concentration of methane in the chamber that enclosed plants with water level below soil surface did not change...
with time. The concentration was close to the atmospheric methane concentration and the rate did not change in twelve days (end of June and first week of July) in these tanks. The rate of emission was initially low in plants that had water at a level of 15cm above the soil surface. At the end of twelve days the average rate of emission increased from $1.05\pm0.18 \text{ mg m}^{-2} \text{ hr}^{-1}$ to $5.97\pm1.66 \text{ mg m}^{-2} \text{ hr}^{-1}$. The rate of emission was high in plants with water level at 30cm above the soil surface. The average rate of emission ranged from $19.8\pm8.9 \text{ mg m}^{-2} \text{ hr}^{-1}$ on the first day of sampling to $84.70\pm39.91 \text{ mg m}^{-2} \text{ hr}^{-1}$ on the twelfth day of sampling.

**Oxidation of methane**

The highest rate of methane oxidation was observed from primary roots followed by roots and rhizomes, shoot parts and the rhizospheric soil (Table 9).

Table 9. Oxidation of methane by parts of plants

<table>
<thead>
<tr>
<th>Parts of Plants</th>
<th>Oxidation of Methane (μg g$^{-1}$ DW hr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoots</td>
<td>14.66±1.69</td>
</tr>
<tr>
<td>Roots and Rhizomes</td>
<td>31.61±11.05</td>
</tr>
<tr>
<td>Primary Roots</td>
<td>91.48±8.05</td>
</tr>
<tr>
<td>Rhizospheric Soil</td>
<td>3.77±0.95</td>
</tr>
</tbody>
</table>

The highest rate of methane oxidation was observed from primary roots followed by roots and rhizomes, shoot parts and the rhizospheric soil.
Results

Methane Production from a Natural Wetland containing Peat Soil

**Characteristic of the Peat collected from Lake Khajjiar in 2004**

The average pH of the peat prior to incubation was 6±2 and it did not differ across the three different layers (0-10, 10-15, 15-20 cm) of the soil core at all the sites. The organic matter content of 15-20cm soil layer was highest followed by 10-15 and 0-10 cm layer at Site A and B at Lake Khajjiar (Table 10).

Table 10. Organic matter content (%) of soil from the two sites at Lake Khajjiar.

<table>
<thead>
<tr>
<th>Sites</th>
<th>0-10cm Soil layer</th>
<th>10-15cm Soil layer</th>
<th>15-20cm Soil layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>42.95</td>
<td>44.51</td>
<td>51.46</td>
</tr>
<tr>
<td>B</td>
<td>37</td>
<td>43</td>
<td>56</td>
</tr>
</tbody>
</table>

The organic matter content of 15-20cm soil layer was highest followed by 10-15 and 0-10 cm layer at Site A and B at Lake Khajjiar (Table 10).

*Methane and Carbon dioxide production from soils at Site-C*

A preliminary experiment was conducted with the three different soil layers at Site-C to determine the production and oxidation capacity of the peat soil at Lake Khajjiar. The experiment was terminated after 15 days. The rate of methane and carbon dioxide production varied across different layers of soil at 25°C, at Site C, Lake Khajjiar (Table 11). The rate of methane production via hydrogenotrophic methanogenesis (soil slurries incubated with methyl fluouride) was less than the total methanogenesis. Respiratory Index (RI) was higher in the 10-15cm and 15-20cm layer compared to the 0-10cm layer. Methane (supplemented externally) was consumed by the three soil layers. The 0-10cm soil layer consumed the most methane followed by the 10-15cm soil layer and 15-20cm soil layer at Site-C. The preliminary experiment showed that methane was produced and also oxidized by the soil at Lake Khajjiar, but the major work with the soil collected from Lake Khajjiar in 2004, focussed on methane production.
Table 11. Rate of methane and carbon dioxide production from soil of 0-10, 10-15, 15-20 cm layers at Site-C

<table>
<thead>
<tr>
<th>Site C</th>
<th>0-10cm Layer</th>
<th>10-15 cm Layer</th>
<th>15-20 cm Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control Mean ± SD</td>
<td>CH$_3$F inhibited samples Mean ± SD</td>
<td>Control Mean ±SD</td>
</tr>
<tr>
<td>CH$_4$ production (µmol g$^{-1}$DW day$^{-1}$)</td>
<td>3.45±0.69</td>
<td>0.9±0.45</td>
<td>1.60±0.47</td>
</tr>
<tr>
<td>CO$_2$ production (µmol g$^{-1}$DW day$^{-1}$)</td>
<td>3.78±1.48</td>
<td>n.a.</td>
<td>2.64±0.35</td>
</tr>
<tr>
<td>RI ((CO$_2$/CH$_4$+CO$_2$))</td>
<td>0.52</td>
<td>n.a.</td>
<td>0.62</td>
</tr>
<tr>
<td>CH$_4$ Consumption (µmol g$^{-1}$DW day$^{-1}$)</td>
<td>13.46±3.51</td>
<td>n.a.</td>
<td>7.76±3.05</td>
</tr>
</tbody>
</table>

Rate of methane, carbon-dioxide and hydrogen production at different temperatures from Site-A and B.

Slurries were prepared with soil of different layers at Site A and Site B and incubated with and without methyl fluoride at different temperatures (4 to 45°C). They differed in their rate of methane, hydrogen and carbon dioxide production.

Site-A

The soil from different depths at Site A was incubated for 30 days. The rate of methane production increased from 4°C until 37°C and then decreased at 45°C in the soil across all layers; 0-10cm, 10-15cm and 15-20cm (Fig.24a). The rate of methane production was highest at the 0-10cm soil layer, followed by the 10-15cm and 15-20cm soil layer.

The addition of methyl fluoride inhibited methane production from acetoclastic methanogenesis. The methane produced in the soils with methyl fluoride is from hydrogenotrophic methanogenesis. The rate of methane production from soil incubated with methyl fluoride was less compared to the soil incubated without methyl fluoride (Fig.24b).
Fig. 24 Variation in the rate of methane production (μmol g⁻¹ DW day⁻¹) from soil of three different depths a) without and b) with CH₃F at Site-A with the rise in temperature.
Fig. 25. The variation in the rate of carbon dioxide production (μmol g⁻¹ DW day⁻¹) from soil of three different depths a) without and b) with CH₃F at Site-A with the rise of temperature. Respiratory Index is represented in open symbols.
 Results

Fig. 26. Steady state concentration of hydrogen gas (ppmv) from soil of three different depths a) without and b) with \( \text{CH}_3\text{F} \) at different temperatures at Site-A

The rate of carbon dioxide production was higher than the rate of methane production from soil incubated without and with methyl fluoride at different layers. The rate of carbon dioxide also increased until 37°C and then decreased at 45°C in soils incubated with and without methyl fluoride (Fig 25a, b).
The respiratory index ($RI = \frac{CO_2}{CO_2 + CH_4}$) was very high (~ 1) at 4°C and decreased (~ 0.5) with the increase in temperature in soils incubated with and without methyl fluoride from 0-10cm layer at Site A (Fig 25a, b).

The steady state concentration of hydrogen gas was low and observed only at 37°C and at 45°C from the 0-10cm soil layer, at 37°C from the 10-15 cm soil layer and from the 15-20 cm soil layer (Fig.26a). In the inhibited soil, the steady state concentration was 25.27±5.54 ppmv at 45°C from the 0-10cm layer (Fig.26b).

**Site B**

The soil from three different layers 0-10 cm, 10-15cm, 15-20 cm at Site B were incubated for 45 days (Fig.27a). The rate of methane production from 0-10cm soil layer at Site-B was higher than 10-15cm and 15-20cm. The rate of methane production was negligible at lower temperatures and increased with the rise in temperature until 37°C and decreased thereafter from soils across different depths.

The rate of methane production from the soils incubated with methyl fluoride (Fig.27b) was lower than the soils incubated without methyl fluoride.

The rate of carbon dioxide production was higher (Fig.28a, b) than the rate of methane production from the soil incubated without and with methyl fluoride at different layers. The rate of carbon-dioxide production increased until 37°C and then reduced at 45°C from the soil of different depth at Lake Khajjiar.

The Respiratory Index (Fig.28a) was around 0.5 in soil at 0-10cm layer. The RI in the other two soil depths was higher than 0-10cm layer in the soils incubated without methyl fluoride.

The Respiratory Index was (Fig.28b) higher in soils incubated with methyl fluoride than soils without incubated with methyl fluoride at Site B.
The steady state concentration of hydrogen gas increased with temperature in the soil incubated with methyl fluoride and without methyl fluoride but the fluctuation was more in the soils without methyl fluoride (Fig.29a, b).

![Graph a)

![Graph b)](https://via.placeholder.com/150)

Fig. 27. The variation in the rate of methane production (μmol g⁻¹ DW day⁻¹) with the rise of temperature at three different soil layers a) without and b) with CH₃F at Site-B.
Fig. 28. The variation in the rate of carbon dioxide production (μmol g⁻¹ DW day⁻¹) with the rise of temperature at three different soil layers a) without and b) with CH₃F at Site-B. Respiratory Index is also represented by open symbols.
Fig. 29. Steady state concentration (ppmv) of hydrogen gas of a) without and b) with CH₃F of the three soil layers at different temperatures at Site-B.
**Hydrogenotrophic Methanogenesis at Site-A and B**

At lower temperature acetoclastic methanogenesis was dominant and with the increase in temperature hydrogenotrophic methanogenesis took over until 37°C at both the sites (Fig.30 a and b). Polynomial trendline was best suited to bring forth the relation ship between hydrogenotrophic methanogenesis and rise in temperature at Site A (order 3; Equation; \( y=-3E-05x^3+0.0018x^2-0.0261x+0.237 \)) and Site-B (order 3; Equation: \( y=-1E-05x^3+0.0003x^2+0.0138x+0.332 \)) The linear rate of methane production decreased above the optimal temperature as well as the fraction of methane from \( \text{H}_2/\text{CO}_2 \). Hydrogenotrophic methanogenesis decreased with depth. This observation was found similar for both the sites. At Site A-the contribution of \( \text{H}_2/\text{CO}_2 \) to methane production increased substantially with the rise in temperature (up to 46% at 37°C in the 0-10cm layer) where as at Site B-hydrogenotrophic methanogenesis was 40% at 4°C and increased up to 70% at 37°C in the 0-10cm layer.

**Fatty Acid Analysis**

At Site-B, propionate (Fig.32b) was not observed in soils incubated over the wide range of temperature except at few temperatures (0.057 \( \mu \text{mol g}^{-1} \text{DW day}^{-1} \) in the 10-15 cm layer at 25°C, 0.001 \( \mu \text{mol g}^{-1} \text{DW day}^{-1} \) in the 0-10cm layer at 37°C, 0.237 \( \mu \text{mol gDW}^{-1} \text{day}^{-1} \) in the 0-10cm layer at 45°C, 0.367 \( \mu \text{mol g}^{-1} \text{DW day}^{-1} \)in the 10-15 cm layer at 45°C and 0.073 \( \mu \text{mol g}^{-1} \text{DW day}^{-1} \) in the 15-20 cm layer at 45°C). The
transient accumulation of propionate was highest at 45°C in the soils incubated with methyl fluoride from 0-10cm and 10-15 cm layer at Site B.

Butyrate accumulated in two samples (data not shown) incubated with methyl fluoride at 11°C (0.14 µM) and 45°C (0.16µM) for the 0-10cm layer only at Site B. Substances coeluting with Butyrate giving a strong signal in the UV detected but not in the RI was observed. No conclusion could be reached for this substance, which was found for nearly all the samples at Site –A and for few at Site-B.

![Acetate accumulation in the soil at Site A incubated with CH₃F at different temperature](image)

![Propionate accumulation in soil at Site-A incubated with CH₃F at different temperature](image)

Fig. 31. Transient accumulation of a) acetate and b) propionate (µmol g⁻¹ DW day⁻¹) in the soil of three different depth incubated with CH₃F at Site A.
Fatty acids were nearly absent (except for acetate in the 10-15 cm soil layer-0.0028 μmol gDW⁻¹ day⁻¹ and 15-20 cm soil layer-0.00383 μmol gDW⁻¹ day⁻¹ in Site B) in the soil before incubation at different temperatures. Post incubation transient accumulation of acetate was dominant followed by propionate and butyrate. At Site-A, fatty acids were not observed in the soil incubated over the wide range of temperature except at 45°C (0.92 μmol gDW⁻¹ day⁻¹ in the 0-10 cm layer and 0.045 μmol g⁻¹ DW day⁻¹). However considerable accumulation of acetate (Fig. 31a) and propionate (Fig. 31b) to a much lesser extent was observed at higher temperatures, in the soils incubated with methyl fluoride at 0-10 cm layer at Site-A. The transient accumulation of acetate (Fig. 31a) was highest at 45°C and then at 37°C in the soils incubated with methyl fluoride at 0-10 cm layer of Site A.

At Site-A, propionate (Fig. 31b) was not observed in the soils incubated over the wide range of temperature except at 45°C (0.133 μmol g⁻¹ DW day⁻¹ in the 0-10 cm layer).

At Site-B, fatty acids were not observed in soils incubated over the wide range of temperature except at 37°C and 45°C. Transient accumulation of acetate (Fig. 32a) was highest at 25°C, and then at 45°C, 37°C in soils incubated with methyl fluoride from 0-10 cm layer at Site B.
Methane produced by acetoclastic pathway was calculated by subtracting the methane produced by hydrogenotrophic methanogenesis (using methyl fluoride) from methane produced by total methanogenesis (without using inhibitor). Significant correlation (Fig.33a) ($p = 0.05$) was observed between acetate accumulation and acetoclastic methane production at the 0-10 cm ($r^2 = 0.886$), 10-15 cm ($r^2 = 0.935$) and 15-20 cm ($r^2 = 0.941$) layers of soil at Site A whereas at Site B (Fig.33b) the correlation was positive but not significant at any of the soil depths.
Results

Acetoclastic methane production against acetate accumulation in three soil depth at Site A

Acetoclastic methane production against acetate accumulation in three soil depth at Site B

Fig. 33 The variation in methane produced by acetoclastic pathway and acetate accumulation in the three soil layers at a) Site A and b) Site B
Structure of the Archaeal Community

Twelve major base pair fragments were detected from the soil samples and their phylogenetic affiliation cited by different workers is given below (Table 12.). The methanogens belonging to the family Methanomicrobiaceae and Methanobacteriaceae are known to utilize the hydrogenotrophic pathway. The methanogens belonging to Methanosoaetaceae utilize acetoclastic pathway whereas the methanogens belonging to Methanosarcinaceae generally utilize the acetoclastic pathway but can also utilize the hydrogenotrophic pathway.

Table 12. Predicted Terminal Restriction fragment (T-RF) length of archaeal 16S rRNA gene sequences from clone libraries and their phylogenetic affiliation

<table>
<thead>
<tr>
<th>T-RF length (bp)</th>
<th>Phylogenetic Affiliation</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>No Affiliation found</td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>Crenarcheota Rice Cluster VI</td>
<td>Chin et al., (1999)</td>
</tr>
<tr>
<td>83</td>
<td>Methanomicrobiaceae</td>
<td>Fey et al., (2001)</td>
</tr>
<tr>
<td>91</td>
<td>Methanobacteriaceae</td>
<td>Chin et al., (1999)</td>
</tr>
<tr>
<td>186</td>
<td>Methanosarcinaceae</td>
<td>Chin et al., (1999)</td>
</tr>
<tr>
<td></td>
<td>Crenarchaeota-Rice Cluster VI</td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>No Affiliation found</td>
<td></td>
</tr>
<tr>
<td>284</td>
<td>Methanosoaetaceae / Rice Cluster V</td>
<td>Chin et al., (1999)</td>
</tr>
<tr>
<td>382</td>
<td>Crenarchaeota-Rice Cluster-III</td>
<td>Weber et al., (2001)</td>
</tr>
<tr>
<td>494</td>
<td>No Affiliation found</td>
<td></td>
</tr>
<tr>
<td>736</td>
<td>Crenarchaeota-Rice Cluster IV</td>
<td>Chin et al., (1999)</td>
</tr>
<tr>
<td>794</td>
<td>Crenarchaeota-Rice Cluster IV</td>
<td>Chin et al., (1999)</td>
</tr>
</tbody>
</table>

Site-A

In the pre-incubated soil samples at Site-A, the relative fluorescence (%) of the dominant base pair fragments were the following (Fig.34a), 91 bp-24%, 185 bp-20%, 284 bp-18%, 396- 21%, in the 0-10cm layer, (Fig. 34b) 91 bp-25%, 185bp-14%, 284 bp-28%, 396- 23%, in the 10-15cm layer, (Fig. 34c) 91 bp-13%, 185bp-23%, 284 bp-20%, 396-18% in the 15-20cm layer

The relative fluorescence (%) of four base pair (91, 185, 284 and 396) fragments was dominant in all the three layers of pre-incubated soil (Fig.34). Thus, for the soils incubated without and with methyl fluoride, the comparison was made with respect to the above-mentioned four base pair fragments at different temperatures.
In the 0-10 cm layer of soil, the relative fluorescence of 91 bp was (Fig. 35a) highest at 25°C and 45°C and lowest at 4°C. The relative fluorescence of 185 bp fragments (Fig. 35b) was highest at 45°C and lowest at 25°C. The relative fluorescence of 284 bp fragments (Fig. 35c) was highest at 4°C and lowest at 15°C. The relative fluorescence of 396 bp fragments (Fig. 35d) was highest at 4°C and 45°C.

In the 0-10 cm layer of soil incubated with methyl fluoride, the relative fluorescence of 91 bp (Fig. 36a) was highest at 45°C and lowest at 11°C. The relative fluorescence...
Fig. 34. Variation in the relative fluorescence (%) of base pairs before incubation from a) 0-10 cm, b) 10-15 cm and c) 15-20 cm layer of soil at Site-A

In the 0-10 cm layer of soil, the relative fluorescence of 91 bp was (Fig. 35a) highest at 25°C and 45°C and lowest at 4°C. The relative fluorescence of 185 bp fragments (Fig. 35b) was highest at 45°C and lowest at 25°C. The relative fluorescence of 284 bp fragments (Fig. 35c) was highest at 4°C and lowest at 15°C. The relative fluorescence of 396 bp fragments (Fig. 35d) was highest at 4°C and 45°C.

In the 0-10 cm layer of soil incubated with methyl fluoride, the relative fluorescence of 91 bp (Fig. 36a) was highest at 45°C and lowest at 11°C. The relative fluorescence
of 185 bp fragments (Fig.36b) was highest at 45°C and lowest at 4 and 11°C. The relative fluorescence of 284 bp fragments (Fig.36c) was highest at 11°C and lowest at 15°C. The relative fluorescence of 396 bp fragments (Fig.36d) was highest at 45°C and lowest at 15°C.

Fig.35 Variation in the relative fluorescence (%) of base pairs a) 91, b) 184, c) 284, d) 396 from soil samples of 0-10 cm layer incubated at different temperatures at Site A
**Results**

**Site B**

In the pre-incubated soil samples at Site-B, the relative fluorescence (%) of the dominant base pair fragments were the following (Fig.37a), 91 bp-40%, 185 bp-20%, 284 bp-13%, 396 bp-13%, in the 0-10cm layer,

(Fig. 37b) 91 bp-50%, 185 bp-19%, 284 bp-9%, 396 bp-8%, in the 10-15cm layer,

(Fig. 37c) 91 bp-25%, 185 bp-9%, 284 bp-19%, 490 bp-17% in the 15-20cm layer

The relative fluorescence of four base pair (91, 185, 284 and 396) fragments were dominant in all three soil layers except in the 15-20cm layer where the fluorescence

---

Fig.36 Variation in the relative fluorescence (%) of base pairs a) 91, b) 184, c) 284, d) 396 from soil of 0-10cm layer incubated with methyl fluoride at different temperatures of Site A.
Results

(\%) of the 396 bp fragment was low and the 490 bp fragment was high. For the soil samples without and with methyl fluoride, the comparison is done in respect to the above four base pair fragments (91, 185, 284, 396) across six temperatures.

Fig. 37 Variation in the relative fluorescence (\%) of base pairs before incubation from a) 0-10 cm, b) 10-15 cm and c) 15-20cm layer of soil at Site-B
In the 0-10cm layer of soil, the relative fluorescence of 91 bp was (Fig.38a) highest at 11°C and lowest at 15°C. The relative fluorescence of 185 bp fragments (Fig.38b) was highest at 25°C and lowest at 15°C, The relative fluorescence of 284 bp fragments
Results

(Fig.38c), was highest at 25°C and lowest at 15°C. The relative fluorescence of 396 bp fragments (Fig.38d) was highest at 4°C and lowest at 15°C. In the 0-10 cm layer of soil incubated with methyl fluoride, the relative fluorescence of 91 bp fragments (Fig.39a) was highest at 45°C and lowest at 4°C. The relative fluorescence of 185 bp fragments (Fig.39b) was highest at 4°C and lowest at 45°C. The relative fluorescence of 284 bp fragments (Fig.39c) was highest at 15°C and lowest at 37°C. The relative fluorescence of 396 bp fragments (Fig.39d) was highest at 45°C and lowest at 37°C.

![Results Diagrams]

Fig.39 Variation in the relative fluorescence (%) of base pairs a) 91, b) 184, c) 284, d) 396 from soil of 0-10 cm layer incubated with methyl fluoride at different temperatures at Site B
In the 10-15cm layer of soil, the relative fluorescence of 91 bp fragments (Fig.40a) was highest 45°C and lowest at 15°C. The relative fluorescence of 185 bp fragments (Fig.40b) was highest at 45°C and lowest at 15 and 25°C. The relative fluorescence of 284 bp fragments (Fig.40c) was highest at 4°C. Fluorescence was not detected at 45°C. The relative fluorescence of 396 bp fragments (Fig.40d) was highest at 45°C and lowest at 15°C.

Fig. 40 Variation in the relative fluorescence (%) of base pairs a) 91, b) 184, c) 284, d) 396 from soil of 10-15cm layer incubated at different temperatures at Site B.
In the 10-15cm layer of soil incubated with methyl fluoride, the relative fluorescence of 91 bp (Fig.41a) was highest at 45°C and lowest at 4 and 11°C. The relative fluorescence of 185 bp fragments (Fig.41b) was highest at 37°C. Fluorescence was not detected at 45°C. The relative fluorescence of 284 bp fragments (Fig.41c) was highest at 4°C Fluorescence was not detected at 45°C. The relative fluorescence of 396 bp fragments (Fig.41d) was highest at 4°C-26%. Fluorescence was not detected at 45°C.

Fig.41 Variation in the relative fluorescence (%) of base pairs a) 91, b) 184, c) 284, d) 396 from soil with methyl fluoride of 10-15cm layer incubated at different temperatures at Site B.
In the 15-20cm layer of samples, the relative fluorescence of 91 bp fragments (Fig.42a) was highest at both 15°C and 25°C. Fluorescence was not detected at 4 and 45°C. The relative fluorescence of 185 bp fragments (Fig.42b) was highest at 4°C. Fluorescence was not detected at 45°C. The relative fluorescence of 284 bp fragments (Fig.42c) was highest at 25°C. Fluorescence was not detected at 45°C. The relative fluorescence of 396 bp fragments (Fig.42d) was highest at 37°C. Fluorescence was not detected at 4, 25 and 45°C.

Fig.42 Variation in the relative fluorescence (%) of base pairs a) 91, b) 184, c) 284, d) 396 from soil of 15-20cm layer incubated at different temperatures of Site B
In the 15-20cm layer of soil samples incubated with methyl fluoride, the relative fluorescence of 91 bp fragments (Fig.43a) was highest at 11°C. Fluorescence was not detected at 45°C. The relative fluorescence of 185 bp fragments (Fig.43b) was highest at 45°C. Fluorescence was not detected at 37°C. The relative fluorescence of 284 bp fragments (Fig.43c) was highest at 4°C. Fluorescence was not detected at 37°C and 45°C. The relative fluorescence of 396 bp fragments (Fig.43d) was only found at 4°C.

Fig.43 Variation in the relative fluorescence (%) of base pairs a) 91, b) 184, c) 284, d) 396 from soil of 15-20 cm layer incubated with methyl fluoride at different temperatures of Site B
**Results**

The response to the addition of alternate electron acceptors and substrates used by methanogens on methane production in Khajiar Soil

Methane production was observed from the soils, collected from the three different depths in the three sites, incubated with competitors for substrates used by methanogens and substrates used by different groups of methanogens at 25°C. Soils incubated without any external additive acted as a control observation.

The soil from the 0-5cm layers at the three sites showed a similar trend in methane production on incubation with sodium sulfate (10mM), sodium molybdate (10mM) and sodium nitrate and for control (Fig.44a). The methane production was highest from all the three sites when incubated without any competitors for the substrate of methanogens. The rate of methane production in control was highest at Site-1 (275.08±56.66 (μmol g⁻¹ DW day⁻¹)) followed by Site-2 (205.77±9.02 (μmol g⁻¹ DW day⁻¹)) and at Site-3 (151.13±31.55 (μmol g⁻¹ DW day⁻¹)). The rate of methane production from control varied significantly from the rate of methane production when incubated with sodium sulfate and sodium molybdate from all the sites. The incubation with nitrate did not yield any substantial methane even after an incubation of 40 days at all the three sites. Sodium sulfate inhibited the production of methane by 90, 97 and 99% at Site-1, 2 and 3 respectively. The addition of molybdate increased methane production by 84, 92 and 85 % with respect to sulfate but also inhibited it by 35.88, 52.05 and 93.65 % with respect to control at Site 1, 2 and 3 respectively.

In the 5-15cm soil layer (Fig.44b), the potential rate of methane production was highest from the control and between the sites it was 219.44±11.72 at Site 2 followed by 69.92±7.59 at Site 3 and then 50.18 ±1.12 at Site 1. The % inhibition of the rate of methane production by sulfate was 99.61, 96.78 and 99.31 % at Site 1, 2 and 3 respectively. The addition of molybdate increased methane production by 16.50, 82.66 and 99.41 % with respect to sulfate but inhibited it by 99.53, 81.43 and 3.89 % with respect to control at Site 1, 2 and 3 respectively.

In the 15-25cm soil layers (Fig.44c), the potential rate of methane production was highest from the control and between the sites it was 167.97±4.21 at Site-1 followed by 143.94 ±14.36 at Site 2 and 11.45±4.39 at Site-3. The % inhibition by sulfate was 90.62, 90.98 and 100.31 % at Site 1, 2 and 3 respectively. The addition of molybdate increased methane production by 69, 65.65 and 100 % with respect to sulfate but inhibited it by 69.01, 73.96 and 98.52 % with respect to control at Site 1, 2 and 3 respectively.
Results

Fig. 44 The variation in the rate of methane production (μmol g⁻¹ DW day⁻¹) on incubation with or without external competitors for substrates used by methanogens from the a) 0-5 cm b) 5-15 cm and c) 15-25 cm of soil layers at three sites at Lake Khajjiar.
Stimulative responses due to the addition of substrate varied in the soil from three different depths and within the three sites (Fig.45). In the 0-5cm soil layers at Site 1 the stimulation in the rate of methane production by H2/CO2 was 133.13% whereas for acetate it was 75.68%. At Site-2, the rate of methane production was inhibited by 5% and 30.21% on addition of H2/CO2 and acetate respectively. In the 5-15cm soil layer at Site-1, the stimulative response of H2/CO2 was 117.72% but the addition of acetate reduced the rate of production by 53.15%. At Site-2 the addition of H2/CO2 and acetate reduced the rate of methane production by 37.19 and 44.11% in the 5-15cm soil layer. At 5-15cm layer of Site-3, the addition of H2/CO2 and acetate stimulated the production by 37.31 and 100.29%. In the 15-25cm soil layers at Site-1 and 2 the addition of acetate and H2/CO2 had inhibitory effect on methane production whereas at Site 3 the addition of H2/CO2 and acetate stimulated methane production by 67.39 and 97.38% respectively.

![Rate of methane production from three soil depths and site](image)

**Fig. 45** The variation in the rate of methane production ($\mu$mol g$^{-1}$ DW day$^{-1}$) on incubation with or without external substrates used by methanogens from the three soil depths at three sites at Lake Khajjiar.

Methane production from control was found to be significantly correlated to organic matter (Spearmann's nonparametric $r^2=0.917$, significant at $p=0.001$ level) (Fig.46).

There was a positive but a low correlation between methane production from control and microbial carbon and microbial biomass (Spearmann’s nonparametric $r^2=0.429$) (Fig.47)

Fig.46 The variation in the rate of methane production ($\mu$mol g$^{-1}$ DW day$^{-1}$) in relation to organic matter (%) from three depths of the three sites.

Fig.47 The variation in the rate of methane production in relation to microbial carbon and biomass from three depths of the three sites.
Methane Production from Natural Wetland containing Mineral Soils

The potential methane production of soils was observed by incubating the soils at four different temperatures.

The rate of methane production increased linearly with the rise in temperature in Bhalswa soil (Fig. 48.a). Potential methane production was observed at 48°C. The rate of methane production increased linearly with the rise in temperature in the sandy soil (Fig. 48.b). Potential methane production was also observed at 48°C. In the garden soil (Fig. 48.c) the rate of methane production hardly increased till 37°C and then it shot to $3.080 \pm 1.07 \text{ mmol g}^{-1} \text{ DW day}^{-1}$ at 48°C. Potential methane production was also observed at 48°C.

A comparison between the potential rate of methane production at 48 °C from different soils shows that the garden soil had the maximum rate of methane production followed by Bhalswa Soil and then Sandy soil.

![Graph a](image1.png)

**The rate of methane production at different temperatures from Bhalswa Soil**

![Graph b](image2.png)

**The rate of methane production at different temperatures from Sandy Soil**
The rate of methane production at four different temperatures from a) Bhalswa soil, b) Sandy soil and c) Garden soil

The response to the addition of competitors and substrates used by methanogens on methane production in Bhalswa Soil

The rate of methane production varied on incubation with different inhibitors at 25 °C from soil of Lake Bhalswa (Fig.49). The addition of sulfate reduced the rate of methane production by 54% and the addition of molybdate reduced the rate by 7%. With respect to sulfate the addition of molybdate recovered the rate of methane production by 50%.

The rate of methane production of soil from Lake Bhalswa also varied on incubation with different substrates at 25 °C (Fig.50). The addition of 0.5 M sodium acetate significantly stimulated rate of methane production to 52.74±1.76 μmol g⁻¹ DW day⁻¹. The rate increased by 51 times compared to the control. The addition of H₂/CO₂ inhibited the rate of methane production. The rate reduced by 0.58 times compared to the control.
Results

Fig. 49. The variation in the rate of methane production (µmol g⁻¹ DW day⁻¹) on incubation with or without external competitors for substrates used by methanogens from soils at Lake Bhalwa.

Fig. 50. The variation in the rate of methane production (µmol g⁻¹ DW day⁻¹) on incubation with or without external substrates used by methanogens from soils at Lake Bhalwa.