CARBON MINERALISATION OF RECLAIMED PEATS FOR AGRICULTURE: EFFECTS OF LIME AND NITROGEN APPLICATION

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Abstract. Liming and nitrogen fertiliser application are common management practice used to achieve optimum production in reclaimed peats for agriculture. The effects of lime and nitrogen addition on carbon mineralisation have been widely studied, but the results are highly varied. These inconsistencies are thought to have been attributed to differences in the quality of substrates in the soils used in those studies. To test whether the effect of lime and nitrogen addition on carbon mineralisation of peats depends on peat substrate quality, two tropical peats varying in carbon chemical structure as determined by the solid-state $^{13}$C nuclear magnetic resonance (NMR) were incubated in the laboratory experiment for 35 days. Carbon mineralisation in peat of high C/N ratio increased with nitrogen addition, but decreased in peat of low C/N ratio. Liming stimulated carbon mineralisation in both peats but the response was greater in peat of high C/N ratio than that of low C/N ratio. Results of this study demonstrate that liming and nitrogen fertiliser application influence carbon mineralisation of peats with the degree of carbon mineralisation varied with the substrate quality of peats.

Keywords: carbon mineralisation, substrate quality, C/N ratio, alkyl C, O-alkyl C

Abstrak. Pengapuran and aplikasi pupuk nitrogen pada tanah gambut yang telah direklamasi dilakukan untuk mencapai produksi yang optimum. Pengaruh pengapuran dan pemupukan nitrogen terhadap mineralisasi karbon sudah banyak dilakukan, akan tetapi hasil yang diperoleh masih sangat bervariasi. Ketidak-konsistennan hasil penelitian ini diduga disebabkan perbedaan kualitas substrat pada tanah yang digunakan dalam penelitian. Untuk menguji apakah pengapuran pengapuran dan pemupukan nitrogen terhadap mineralisasi karbon ditentukan oleh kualitas substrat pada gambut, dua gambut dari daerah tropik dengan komposisi kimia yang berbeda yang ditetapkan dengan solid-state $^{13}$C nuclear magnetic resonance (NMR) diinkubasi selama 35 hari pada suatu percobaan inkubasi di laboratorium. Mineralisasi karbon pada gambut dengan C/N rasio yang tinggi meningkat dengan perlakuan pemupukan nitrogen, tetapi menurun pada gambut dengan C/N rasio yang rendah. Pengapuran meningkatkan mineralisasi karbon pada ke dua gambut dengan jumlah karbon yang terminalisasi lebih besar pada gambut dengan C/N rasio yang tinggi dibanding dengan gambut dengan C/N rasio yang rendah. Hasil penelitian ini memperlihatkan bahwa pengapuran dan pemupukan mempengaruhi mineralisasi karbon pada gambut dengan jumlahkarbon yang terminalisasi bervariasi berdasarkan kualitas substrat gambut.

Kata-kunci: mineralisasi karbon, kualitas substrat, C/N rasio, C-alkil, C-O-alkil
INTRODUCTION

Peatlands in Indonesia cover from 16.8 to 27.0 million ha (Page and Banks, 2007), representing about 5% of global world peatlands and 50% of tropical peatlands in the world (Hooijer et al., 2010). Due to pressure for land, a large part of natural Indonesian tropical peatlands has been and is presently being reclaimed for agricultural purposes (MacKinnon et al., 1996). The common practices associated with the reclamation of peatlands for agriculture in Indonesia include nitrogen fertilizer and lime applications (Andriesse, 1997). Lime is added to the peatlands to neutralise the acidifying effect of the fertilizer and specifically the natural acidity of peat soils in order to achieve optimum pH for plant growth. Moreover, nitrogen fertiliser has been applied to peat soils with the primary aim of improving nitrogen status, which may negatively impact on the productivity of peatland ecosystems.

The effects of nitrogen fertilizer and lime applications on emission of CO₂ from soils have been widely studied, but the results are highly diverse. Previous studies have shown that liming acidic soils increased carbon mineralisation (Fuentes et al., 2006; Geissen and Brummer, 1999) and dissolved organic carbon (Curtin et al., 1998; Motavalli et al., 1995). However, several studies have indicated that no differences in dissolved organic carbon and carbon mineralisation between limed and unlimed plots (Borken and Brumme, 1997). Results of nitrogen fertiliser experiments in mineral soils and peatlands showed that the addition of supplementary N can enhance microbial activity (Allison et al., 2009; Bradley et al., 2000; Corbeels et al., 1999; Lund et al., 2009). However, suppressed microbial activity with nitrogen addition was noted in other experiments (Allison et al., 2008; Keller et al., 2005). Hence, the relative contribution of nitrogen fertiliser and lime applications on the carbon mineralisation of peatlands remains uncertain.

These inconsistencies have been attributed to differences in type of nitrogen fertiliser used time scale of the studies. Another factor that may contribute to the inconsistency is differences in the quality of substrates in the soils used in those studies (Henriksen and Breland, 1999; Vance and Chapin, 2001). The objective of this study was to determine changes in C mineralisation of reclaimed peats in response to nitrogen addition when added singly or in combination with lime. To test whether these effects varied with the quality of substrates, two tropical peats varying in carbon chemical structure as determined by the solid-state ¹³C nuclear magnetic resonance (NMR) were used.
MATERIALS AND METHODS

Peat sampling and characteristics

The samples used for this study were collected from two sites, Pulau Damar, PD-9 (2°25’ S, 116°46’ E) and Gambut, G-7 (03°15’ S, 114°42’ E), on peat soil in the Barito Basin, Indonesia. For several decades, peats in this area have been used for agricultural purposes. At both sites, peats were sampled from the top 20 cm using a cylindrical core (10 cm diameter). Peat samples were collected from the 0-20 cm layer at each site using a cylindrical core (10 cm diameter) at 5 locations and combined to give a single composite sample.

Degrees of decomposition of peat (rubbed fibre content, the von Post scale and phyrophosphate index) were determined by the method of Parent and Caron (1993). Sub-samples of each peat were oven-dried at 70°C for dry-soil determination. Oven-dried peats were then milled to pass a 2-mm sieve prior to physical and chemical analyses. A portion of each sample was ashed to quantify the total ash content, while total carbon and nitrogen were determined by combustion on a Leco CN2000 analyser. The particle density of peat was determined by the method of Blake and Hartge (1996), and the pH was determined in water (vol soil:vol water = 3 : 50) using a glass electrode (Karam, 1993).

Nuclear magnetic resonance (NMR) spectroscopy of peats

The chemical nature of the carbon present in each peat was quantified using solid-state $^{13}$C Nuclear Magnetic Resonance (NMR) spectroscopy. A conventional cross-polarisation pulse sequence (Wilson, 1987) was used with a 1000 µs contact time. The NMR spectra were divided into seven chemical shift regions according to the chemical types of carbon as follows: 0-45 ppm (alkyl C), 45-60 ppm (N-alkyl/methoxyl C), 60-95 ppm (O-alkyl C), 95-110 ppm (di-O-alkyl C), 110-145 ppm (aromatic C), 145-165 ppm (phenolic C), and 165-215 ppm (amide/carboxyl C). The total signal intensity and the proportion contributed by each type of C were determined by integration of the spectral region and corrected for the presence of first order spinning sidebands.

Incubation procedure

An appropriate mass of each peat was placed into a 130-mL container (diameter 5.0-cm). In limed-treated samples, 110-mg CaO was added homogeneously to the peat, and 13-mg KNO$_3$ was applied to the peat in N-treated samples. The amounts of lime and nitrogen applied to the peats were equivalent to the common liming and N fertiliser practices of 10 Mg CaCO$_3$ and 92 kg N ha$^{-1}$ year$^{-1}$ in agricultural peatlands in Indonesia,
respectively. The mass of peat placed into the container was calculated in order to obtain the same bulk density as that measured in the field after compacting the peat in each container to a depth of 2.0 cm. Distilled water was added drop-wise using a fine jet pipette to obtain 50, 60, 70 and 80 % WFPS. Carbon mineralisation of peats was monitored using a Servomex 1450 infrared gas analyser (Servomex, UK).

Statistical analysis

Statistical analysis of experimental data was accomplished by analysis of variance (ANOVA) using a completely randomised factorial design using the package GenStat 12th Edition (Payne 2008). The data were checked for normal distribution with the Shapiro–Wilk test. In the case of significance in ANOVAs, means were compared by the least significant difference (LSD) multiple comparison procedure at P<0.05.

RESULTS AND DISCUSSION

Chemical and physical properties of peat

The two peats used in this study varied widely in physical and chemical characteristics, probably due to difference in the extent of decomposition. G-7 was the least decomposed peat (fibric) and PD-9 was moderately decomposed peat (hemic) based on the von Post’s and rubbed fibre content data (McKinzie, 1974; Parent and Caron, 1993). The most obvious difference in the physical and chemical properties of the two peats was bulk density, carbon contents and C/N ratio. Details of selected physical and chemical characteristics of soils are given in Table 1.

Table 1. Physical and chemical characteristics of the peats.

<table>
<thead>
<tr>
<th>Soil Characteristics</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G-7</td>
</tr>
<tr>
<td>Degree of decompositio</td>
<td>H2</td>
</tr>
<tr>
<td>Von Post’s index</td>
<td></td>
</tr>
<tr>
<td>Rubbed fibre content (%)</td>
<td>42</td>
</tr>
<tr>
<td>Pyrophosphate index</td>
<td>25</td>
</tr>
<tr>
<td>Ash content (g ash.kg⁻¹ soil)</td>
<td>24</td>
</tr>
<tr>
<td>Bulk density (Mg.m⁻³)</td>
<td>0.16</td>
</tr>
<tr>
<td>Particle density (Mg.m⁻³)</td>
<td>1.31</td>
</tr>
<tr>
<td>pH (H₂O)</td>
<td>3.5</td>
</tr>
<tr>
<td>pH (0.01 M CaCl₂)</td>
<td>2.7</td>
</tr>
<tr>
<td>Carbon (g C. kg⁻¹ soil)</td>
<td>729</td>
</tr>
<tr>
<td>Nitrogen (g N. kg⁻¹ soil)</td>
<td>13</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>56.1</td>
</tr>
</tbody>
</table>
Carbon chemistry of peat

Chemical shift region 0-45 ppm of PD-9 was higher than that of G-7. The chemical shift region between 0 and 45 ppm comprises signal intensity of alkyl carbon, i.e. in fatty acids and paraffinic structures. The G-7 peat had higher proportion of O-alkyl C compared to the PD-9 peat (Table 2), suggesting the presence of a higher proportion of carbohydrate in G-7 than in PD-9. The chemical shift for di-O-alkyl C (95-110 ppm) of both peats was dominated by signal at 104 ppm, suggesting at least a portion of the carbohydrate carbon existed as polysaccharides. Difference in the substrate quality for both peats is also revealed by higher ratio of alkyl C to O-alkyl C from the $^{13}$C CP/MAS NMR data for PD-9 than G-7. The decrease in the proportion of O-alkyl C and increase in the proportion of alkyl C as decomposition proceeded suggests that the ratio of alkyl C to O-alkyl C may provide a sensitive index of the extent of decomposition (Baldock et al., 1997; Webster et al., 2000).

Table 2. Relative carbon distribution (%) in different regions of chemical shift (ppm) and ratios of alkyl C to O-alkyl C calculated from the $^{13}$C NMR spectra

<table>
<thead>
<tr>
<th>Chemical Shift Region (ppm)</th>
<th>Chemical Assignment</th>
<th>Peat Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>G-7</td>
</tr>
<tr>
<td>0 – 45</td>
<td>Alkyl</td>
<td>25</td>
</tr>
<tr>
<td>45 – 60</td>
<td>N-Alkyl/Methoxyl</td>
<td>7</td>
</tr>
<tr>
<td>60 – 95</td>
<td>O-Alkyl</td>
<td>21</td>
</tr>
<tr>
<td>95 – 110</td>
<td>Di-O-Alkyl</td>
<td>8</td>
</tr>
<tr>
<td>110 – 145</td>
<td>Aromatic</td>
<td>22</td>
</tr>
<tr>
<td>145 – 165</td>
<td>Phenolic</td>
<td>9</td>
</tr>
<tr>
<td>165 – 190</td>
<td>Amide/Carboxyl</td>
<td>6</td>
</tr>
<tr>
<td>190 – 215</td>
<td>Ketone</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Alkyl/O-Alkyl</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Carbon mineralisation

Carbon mineralisation of peat G-7 treated with lime, nitrogen fertiliser and combined lime with nitrogen fertiliser varied between 735 to 879 µg CO$_2$-C g$^{-1}$ peat during 35-day incubation (Figure 1). These rates were 8-29% higher than the CO$_2$ production of peat in the control treatment. Unlike G-7, the CO$_2$ production of the control and nitrogen-treated peats in PD-9 decreased from 820 to 804 µg CO$_2$-C g$^{-1}$peat over the incubation period (Figure 1). No changes in C mineralisation in PD-9 were observed when nitrogen was applied in conjunction with the lime. Both G-7 and PD-9 had similar
nitrogen contents, but the carbon content of G-7 was much higher than that of PD-9. Consequently, addition of supplementary nitrogen to G-7 enhanced C mineralisation, consistent with the generalised concept of increasing C mineralisation with decreasing C/N ratio. Results indicated that liming alone only increased C mineralisation to a small extent. However, when lime was added in combination with nitrogen, the CO₂ production increased significantly, indicating that G-7 was a nitrogen-limited peat.

In contrast to the G-7 peat, data on cumulative C mineralisation suggested that the carbon mineralisation in the PD-9 peat was suppressed by nitrogen addition (Figure 1). This finding is in agreement with previous studies (Aerts and Toet, 1997; Amador and Jones, 1993). The suppressions of soil respiration observed by these authors were attributed to changes in soil pH. All of these authors used ammonium salts to supply nitrogen. In general, ammonium addition to soils results in a reduction of the pH due to nitrification of the supplied ammonium. Generally, decreases in pH result in decreased microbial activity. In this experiment, potassium nitrate was used for nitrogen supply in order to minimise the pH effect. No reduction in pH was observed in nitrogen-treated peat of G-7 or PD-9 (Figure 2). Therefore, a different mechanism must account for the suppression of C mineralisation when N was added to PD-9. Carbon availability to microbes may be reduced by condensation of humus with added nitrogen (Nohrstedt et al., 1989). Fungal ligninolytic activity may be suppressed by nitrogen addition (Keyser et al., 1978). As easily decomposable material such as polysaccharides are embedded in the lignin matrix (Fog, 1988); therefore, when lignin degradation is retarded, these easily
utilisable polysaccharides may not become available to the microbial community (Thirukkumaran and Parkinson, 2000).

Figure 2. Effect of liming and nitrogen addition on pH after 35 days incubation period. L0, without lime amendment; L1, with lime amendment; N0, without nitrogen amendment; N1, with nitrogen amendment. Bars indicate mean ± standard error (n=3). Similar letters above columns indicate no statistical difference between the treatments based on the LSD test at P <0.05.

It appears that microorganisms in the PD-9 are carbon limited (Fig. 1). This assumption appears to be reasonable given that the $^{13}$C CP/MAS NMR spectra of both peats revealed that the PD-9 had a lower proportion of O-alkyl C compared with the G-7 (Table 2). Previous studies show that carbon mineralisation was related to the proportion of O-alkyl C estimated from $^{13}$C NMR (Parfitt and Salt, 2001; Webster et al., 1997). This finding is consistent with hypotheses based on the concept of microbial C versus N limitation. Carbon mineralisation generally responded most strongly to nitrogen addition when organic carbon was abundant and in soils characterised by high C/N ratio, such as found for peat G-1 (Table 1). However, in soils with relatively low C/N ratio, such as found in peat PD-9 (Table 1) addition of nitrogen did not increase carbon mineralisation, as organic carbon was limited. The effect of nitrogen addition on carbon mineralisation with the extent of mineralisation dependent on C/N ratio has also been observed in other studies (Mary et al., 1996; Vance and Chapin, 2001).

Lime application enhanced C mineralisation rates in both peats, but the response of carbon mineralisation to liming was greater in G-7 than in PD-9. Liming on G-7 and PD-9 resulted in 15% and 3% higher cumulative C mineralisation, respectively, than peats without liming (Fig. 1). The different response of CO$_2$ production to liming in the G-7 and PD-9 peats suggested that the carbon mineralisation in the two peats was controlled by different factors. Generally, lime application to acidic soils increased soil pH (Nilsson
et al., 2001; Wanner et al., 1994). In this experiment, the pH of limed PD-9 and G-7 peats was 1.2 units and 0.9 units higher than unlimed peats (Figure 2), suggesting that the different response of carbon mineralisation to liming of the two peats may be related to the extent of pH alteration. The increased C mineralisation may have been due to the proliferation of microbial species already present in the peats that were relatively inactive before liming. The greater response of C mineralisation in G-7 to liming than in PD-9 was also probably due to differences in substrate quality and bioavailability that may change after liming. This may be expected since PD-9 was a more decomposed peat than G-7 (Table 1). The limed PD-9 probably consisted of less bioavailable carbon compounds and the microorganisms may therefore have been more carbon limited than in the G-7, which is consistent with lower ratio of alkyl C to O-alkyl C in G-7 than that in PD-9 (Table 2). This result is in accordance with that observed by Andersson and Nilsson (2001) who showed that increased soil respiration following lime application was higher in less decomposed compared to that in more decomposed organic matter.

CONCLUSIONS

Nitrogen addition to the peat influences carbon mineralisation; the effect varied with substrate quality of peats. The presence of nitrogen in peat of high C/N ratio stimulated carbon mineralisation, whereas carbon mineralisation in the peat of low C/N ratio decreased with nitrogen addition. Liming increased carbon mineralisation in both tropical peats with the extent the increase being dependent on the substrate quality of peat.

REFERENCES


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