Phosphate and Nitrate Release from Mucky Mineral Soils

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ABSTRACT

High-organic (mucky) mineral soils make a small proportion of the Canadian agricultural land but are highly productive, especially for organic farming. Although these high-quality soils may release large amounts of nitrate and phosphate to the environment, there is yet no reliable agro-environmental indicator for managing N and P compared to the adjacent mineral and organic soils. Our objective was to quantify the N mineralization and P environmental risks of mucky mineral soils. Nine Canadian soil series (eight Orthic Humic Gleysols and one Terric Humisol with three variants) were analyzed for texture, pH(CaCl2), total C and N, oxalate and Mehlich-III (M-III) extractable P, Al and Fe, and water-extractable P (Pw). Soil texture varied from loamy sand to heavy clay, organic carbon (OC) content ranged from 14 to 392 g·OC·kg−1, total N from 1.21 to 16.38 g·N·kg−1, and degree of P saturation (DPS M-III) percentage between 0.3% and 11.3%. After 100 d of incubation, soils released 31 to 340 mg·N·kg−1. The N mineralization rate was closely correlated to organic matter content (r = 0.91, p < 0.01). Sandy to loamy soils released 1.2 - 1.8 kg·N·ha−1·d−1 compared to 1.6 - 2.4 kg·N·ha−1·d−1 for clayey soils, 2.0 - 2.8 kg·N·ha−1·d−1 for mucky clayey soils and 2.6 - 2.7 kg·N·ha−1·d−1 for Humisol. For (P/[Al + 3Fe]) M-III ratios of mucky clayey soils below 4.5%, water-extractable P did not exceed threshold of 9.7 mg Pw L−1. Mucky clayey soils could be managed for N similarly to Humisol and for P with (P/[Al + 3Fe]) M-III percentage not exceeding 4.5%.

Keywords: Degree of Phosphate Saturation; Gleysol; Humisol; Organic Nitrogen Mineralization; Zero-Order Kinetics

1. Introduction

Mucky soils occupy a small portion of the agricultural area in the St-Lawrence Lowlands, Québec, Canada, but have suitable physical, chemical, and biological soil quality attributes for vegetable cropping especially under organic farming. In Canada, the distinction between mineral soils and organic soils is based on the organic carbon content, mineral soils showing 17% OC or less by weight [1]. Mineral soils containing more than 9% OC by weight are classified as mucky soils [2] and soils high in organic carbon (4% - 9% OC) [3] as weakly mucky.

Soil quality is defined as soil’s capacity to function within ecosystem to sustain biological productivity, maintain environmental quality and promote plant and animal health [4,5]. Total C and N as well as plant-available mineral N and phosphate are chemical indicators of soil quality. Mucky mineral soils may release large amounts of nitrate and phosphate to the environment but there are no well documented indicators for safely managing N and P.

In average, the arable layer of prairie mineral soils contain 0.65 - 3.21 g total N·kg−1 [6] compared to 3.3 to 24.5 g total N·kg−1 for organic soils [7]; 93% - 97% of this N is in organic form [8]. In general, 1% - 3% of total organic N is converted to mineral N during the growing season [8]. Hence, potentially mineralizable N appears to be considerable in mucky mineral soils.

On the other hand, soil P release depends largely on the amount of Al and Fe oxy-hydroxides in both mineral [9] and organic [10] soils. The degree of phosphate saturation based on the oxalate method (DPSox) has been proposed to assess P environmental risk [11]. The DPSox is the ratio between oxalate-extractable P and P sorption capacity represented by oxalate-extracted Al and Fe oxy-hydroxides corrected by a factor for maximum sorption. The DPSox should not be allowed to exceed 25% to avoid polluting groundwater or waters discharged by subsurface drainage. For acid coarse-textured soils of Québec, this critical value corresponded to water-soluble P of 9.7 mg Pw L−1 [12]. It is noteworthy that this critical
DPS_{ox} value cannot be applied to pollution by runoff waters because it is assumed that all extra water is evacuated through the subsurface water system where total P concentration must not exceed 0.03 mg·P·L^{-1} [9].

Because the oxalate method is not a routine method in North American laboratories, [12] proposed using \((P/Al)_{M-III}\) or \((P/(Al + Fe))_{M-III}\) percentages as DPSM_{III}. In general, the Mehlich-III extracted Fe did not add significant information when relating DPSM_{III} to DPS ox. Nevertheless, [13] argued that Al and Fe should be amalgamated to reflect soil’s capacity to sorb P. The \((P/Al)_{M-III}\) (mg·kg^{-1}) ratio equaled 1.39 × (P/(Al + Fe))_{M-III} (mmol·kg^{-1}) with \(r^2 = 0.99\) in Quebec soils [9]. The \((P/Al)_{M-III}\) ratio was found to be superior to \(P_{M-III}\) alone to classify soil P fertility according to probability of crop response to added P [14], indicating that the plant must compete with soil sorbents for available phosphate. Because the Mehlich-III method ineffectively extracted Fe in organic soils it was proposed inflating extracted Fe by a factor of 5, i.e., DPSM_{III-ox} = 100(P/(Al + γFe))_{M-III} where \(γ = 5\) [10]. The value for \(γ\) could be adapted for managing P in mucky mineral soils.

Our objectives were 1) to determine potentially mineralizable organic N in mineral, mucky mineral and organic soils; and 2) to propose a critical DPSM_{III} for mucky mineral soils that prevents environmental P pollution of groundwater.

2. Material and Methods

2.1. Soil Classification

The arable layers of soils in the flat landscape of the St-Lawrence River are made of marine deposits of the Champlain Sea as well as estuarine, glacial and fluvial deposits from the Post-Champlain era. The climate is temperate continental with annual precipitation of 1000 mm (30% - 40% in the summer season). The frost-free season (90% probability) is 169 days; there are 1939 - 2125 degree-days exceeding 5°C, indicating favorable conditions for cropping.

We investigated nine soil series [3,15] as follows: Aston (AS) loamy sand, Des Chenaux (CH) loam, Du Jour (DJ) clay loam, Laplaine (LP) clay, Massueville (MS) sandy loam, Providence (PV) heavy clay, Sainte-Rosalie (RO) clay, Saint-Urbain (UB) heavy clay, and Verchères (VE) organic soil, located on the IRDA research organic farm at St-Bruno-de-Montarville near Montréal, Québec, Canada (45°33'13"N, 73°20'58"W).

Along a gradient from mineral to organic materials, the texture of mineral and mucky mineral soils varied from sandy to clayey material. A gradient of soil series in the same catena can avoid comparing soils with wide differences in mineralogy and genesis. Soils were classified as Orthic Humic Gleysol (AS, CH, DJ, LP, MS, PV, RO, and UB) or Terric Humisol (VE).

For the N incubation study, we collected eleven surface soil (Ap or Op horizon) samples from the eight mineral soil series and the three variants of the organic soil series. For the P study, we collected 80 surface soil samples varying in physical and chemical properties.

2.2. Soil Analysis

The pH was measured in 0.01M CaCl₂ (1:2 for mineral soils and 1:4 for organic soils). The P, Al and Fe were extracted using the Mehlich III [16] and the acid oxalate methods [17] for comparison with other studies on mineral and organic soils. The Mehlich-III extracting solution is made of 0.2 \(M\) \(CH_2COOH\), 0.25 \(M\) \(NH_4NO_3\), 0.015 \(M\) \(NH_4F\), 0.013 \(M\) \(HNO_3\), and 0.001 \(M\) EDTA. The oxalate extraction solution comprises 0.2 \(M\) \((NH_4)_2C_2O_4\) and 0.2 \(M\) \(H_2C_2O_4\), adjusted at pH 3. Water soluble P was extracted according to [18]. Soil extracts were quantified by ICP-OES (Inductively Coupled Plasma—Optical Emission Spectroscopy). Total C and N were determined using the LECO CR-412 analyzer and by micro-Kjeldahl [19], respectively.

Bulk density was determined using the cylinder method [20]. Soil texture was determined by sedimentation after destroying organic matter with peroxide (H₂O₂, 30%) for soils containing more than 5% organic matter [21].

2.3. Soil Incubation

An amount of 75 g of fresh 8-mm sieved soils was incubated in duplicate at 30°C and 80% relative air humidity in 400-mL jars. Soil moisture was maintained at approximately 60% of field capacity with deionized water. Soils were extracted with 2 N KCl [22] after 0, 10, 20, 30, 40, 60, 80, and 100 d of incubation and analyzed for water soluble P. Soil moisture was maintained at approximately 60% of field capacity with deionized water. Soils were extracted with 2 N KCl [22] after 0, 10, 20, 30, 40, 60, 80, and 100 d of incubation and analyzed for water soluble P. Soil moisture was maintained at approximately 60% of field capacity with deionized water. Soils were extracted with 2 N KCl [22] after 0, 10, 20, 30, 40, 60, 80, and 100 d of incubation and analyzed for water soluble P.

Net mineralization of organic N was modeled by zero-order kinetics as follows:

\[
N_t = k t + N_i
\]

where \(k\) is mineralization rate (mg·kg^{-1}·d^{-1}), \(N_i\) is mineral N extracted at time zero (mg·N·kg^{-1}), and \(N_t\) is mineral N extracted (mg·N·kg^{-1}) at time \(t > 0\) (d). Mineralized N was measured as \(N_t - N_i\).

2.4. Soil P Saturation

The DPS_{ox} was computed as follows [11]:

\[
\text{DPS}_{ox} (%) = 100 \frac{P_{ox}}{\alpha_w (Al_{ox} + Fe_{ox})}
\]

where \(P_{ox}, Al_{ox}\) and \(Fe_{ox}\) expressed in mmol·kg^{-1}, are extracted by the acid ammonium oxalate method [17] and is maximum saturation factor for total sorption (\(\alpha_w = \ldots\))
0.5 for mineral soils and 0.4 for organic soils). The \( \alpha_m \) factor was less for organic soils to account for competition of organic ligands for sorption sites [23]. References [10,12] suggested the following equation for \( \text{DPS}_{\text{M-III}} \):

\[
\text{DPS}_{\text{M-III}} = 100 \frac{P_{\text{M-III}}}{A_{\text{M-III}} + \gamma Fe_{\text{M-III}}}
\]

where \( P_{\text{M-III}} \), \( A_{\text{M-III}} \), and \( Fe_{\text{M-III}} \), expressed in mmol \cdot kg\(^{-1} \), are extracted by the Mehlich III method [16] and \( \gamma = 0 \) or \( \gamma = 1 \) for mineral soils [12,13] and \( \gamma = 5 \) for organic soils [10].

### 2.5. Statistical Analysis

The zero-order N mineralization model was evaluated using linear regression [24]. Factor \( \gamma \) was obtained by relating \( \text{DPS}_{\text{M-III}} \) to \( P_w \) and optimizing the relationship using the Cate-Nelson partitioning procedure where a maximum number of points are allotted to true negative and true positive quadrants [25].

When proportions are analyzed statistically, the results are biased by data redundancy, scale dependency and inherent non-normal distribution [26]. One proportion is always redundant because it is computed by difference between 100% (or the scale of measurement) and other proportions or concentrations. Scale dependency is due to the fact that when expressing the proportions on different scales of measurement (e.g., dry or wet mass basis), the interpretation of the results of the statistical analysis will differ. Inherent non-normal distribution refers to the closed compositional space constrained between zero and the unit of measurement rather than ranging across the real space \(( \pm \infty \)) as is the case for a normal distribution. The log ratios avoid these problems and are most appropriate for the multivariate analysis of compositional data without bias [27-29].

The isometric log-ratios (ilr) project compositional data into a Euclidean space of D-1 non-overlapping orthogonal log-contrasts, also called orthonormal balances or “coordinates” [28]. A system of balances is formalized by a sequential binary partition (SBP), a \((D-1) \times D\) matrix, in which parts labeled “+1” (group numerator) are contrasted with parts labeled “-1” (group denominator) in each ordered row until the \((+1)\) and \((-1)\) subsets each contain a single part. For the \(r\)th row of the SBP matrix, the balances are computed as follows:

\[
ilr_r = \sqrt{\frac{r_s \ln g(c_1^r)}{r_s + s_j} \ln g(c_1^-)}
\]

where \( r \) is the number of components in the \((+1)\) group, \( s \) is the number of components in the \((-1)\) group, \( g(c_1^r) \) is the geometric mean of components at numerator \((+1)\) group and \( g(c_1^-) \) is the geometric mean of components at denominator \((-1)\) group. Each contrast multiplied by an orthogonal coefficient is a coordinate in the Euclidian space. In the case of N mineralization, the two balances include a log contrast between C and N (the classical C/N ratio) and a contrast between the C and N pools and \( F_v \), the filling value between 100% and proportions of C and N.

The balance concept provides the Euclidean geometry required to compute a multivariate compositional distance called “Aitchison distance” \((A)\), between two equal-length compositions \(x\) and \(y\) (referential composition) [30] as follows:

\[
A = \sqrt{\sum_{i=1}^{D-1} (\text{ilr}_i - \text{ilr}_j)^2}
\]

Using the most favorable composition for N mineralization as referential composition, the greater the \( A \), the lesser is the rate of organic N mineralization in soils. The \( A \) thus provides a means to classify soils along a gradient of N mineralization potentials.

### 3. Results and Discussion

#### 3.1. Soil Properties

Soil properties are presented in Table 1. Total N varied between 1.2 and 16.4 mg \cdot kg\(^{-1} \), within ranges reported by [6] for Canadian mineral soils and by [7] for Canadian organic soils. The C/N ratios ranged between 10.8 and 23.9, \( i.e. \), lower than the critical value of 30 for N mineralization [8]. Little correlation was found between pH and N mineralization in 20 Québec mineral soils in the pH(CaCl\(_2\)) range of 5.3 - 7.3 [31]. There is no nitrate production in organic soils at pH(CaCl\(_2\)) values below 4.5 [32]. Therefore, pH did not appear to limit nitrification, except possibly for AS, where pH was close to 5.0.

In the P study, there were 36 mineral soil samples (\(<4\%\) OC), 30 mucky clayey soil samples (4% < OC \(\leq\) 17%) and 14 organic soil samples (>17% OC) varying in physical and chemical properties (Table 2). The P, Al and Fe extracted by the Mehlich-III and oxalate methods were within ranges reported by [9] for Canadian podzolic and gleysolic soils and by [10] for Canadian organic soils (Table 2).

#### 3.2. Mineralization of Organic N

The coefficients of variation of mineral N concentrations varied between 3 and 9%. The zero-order kinetics models showed high \( r^2 \) values (Table 3), indicating that such models reliably assessed N mineralization rates. The N mineralization rate was closely related to organic matter content \((r = 0.91)\) as reported elsewhere [7,8,31]. In mineral soils, N mineralization rate varied between 0.32 and 0.54 mg N·kg\(^{-1}·d\(^{-1}\), within range between 0.24 and 0.60 mg N·kg\(^{-1}·d\(^{-1}\) obtained by [33]. The N mineralization rate ranged between 1.06 and 1.58 mg N·kg\(^{-1}·d\(^{-1}\) in...
Table 1. Soils properties for the N incubation study.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Ap</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>BD</th>
<th>SOM</th>
<th>SOC</th>
<th>SON</th>
<th>C/N</th>
<th>pH(CaCl₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>%</td>
<td>g cm⁻³</td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>26</td>
<td>81</td>
<td>4</td>
<td>15</td>
<td>1.44</td>
<td>24</td>
<td>14</td>
<td>1.21</td>
<td>11.6</td>
<td>5.36</td>
</tr>
<tr>
<td>DJ</td>
<td>22</td>
<td>39</td>
<td>23</td>
<td>38</td>
<td>1.38</td>
<td>28</td>
<td>16</td>
<td>1.32</td>
<td>12.1</td>
<td>5.11</td>
</tr>
<tr>
<td>AS</td>
<td>28</td>
<td>83</td>
<td>4</td>
<td>13</td>
<td>1.52</td>
<td>29</td>
<td>17</td>
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<tr>
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<td>27</td>
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<td>17</td>
<td>1.54</td>
<td>11.0</td>
<td>6.73</td>
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<tr>
<td>PV</td>
<td>26</td>
<td>6</td>
<td>34</td>
<td>60</td>
<td>1.56</td>
<td>31</td>
<td>18</td>
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<td>59</td>
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<td>0.68</td>
<td>114</td>
<td>66</td>
<td>4.00</td>
<td>16.5</td>
<td>5.05</td>
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<td>VEp</td>
<td>23</td>
<td>20</td>
<td>23</td>
<td>57</td>
<td>0.83</td>
<td>153</td>
<td>89</td>
<td>5.10</td>
<td>17.4</td>
<td>4.97</td>
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<td>CH</td>
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<td>22</td>
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<td>315</td>
<td>183</td>
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<td>0.34</td>
<td>676</td>
<td>392</td>
<td>16.38</td>
<td>23.9</td>
<td>5.60</td>
</tr>
</tbody>
</table>

§See text for full names of soil series; †Phase and variant of the VE series: high SOM mineral layer (VEp), shallow organic variant (VEs), deep organic variant (VEd); Ap = thickness of the arable layer; BD = soil bulk density; SOM = soil organic matter; SOC = soil organic carbon; SON = soil organic nitrogen. Mineral, mucky mineral and organic soils separated by horizontal lines.

Table 2. Range of mineral, mucky mineral and organic soils properties for the P saturation study.

<table>
<thead>
<tr>
<th>Clay</th>
<th>SOC</th>
<th>P_M-III</th>
<th>Al_M-III</th>
<th>Fe_M-III</th>
<th>DPS_M-III</th>
<th>P_m</th>
<th>Al_m</th>
<th>Fe_m</th>
<th>DPS_m</th>
<th>P_v</th>
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<tbody>
<tr>
<td>%</td>
<td>g kg⁻¹</td>
<td>%</td>
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<td>mg kg⁻¹</td>
<td>%</td>
<td>mg L⁻¹</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Mineral soils (n = 36; γ = 1; α_m = 0.5)

Min 9 7 4 948 158 0.3 329 2267 2826 9.6 2.7
Max 71 34 203 1485 397 11.3 1018 8179 10,188 28.4 17.3
Mean 50 19 61 1111 271 4.2 623 3348 5229 18.7 8.2
SD 17 7.2 39 120 61 2.3 162 1156 1557 4.5 4.1

Mucky mineral soils (n = 30; γ = 3; α_m = 0.45)

Min 28 43 10 729 142 0.6 541 2434 4119 14.3 3.1
Max 76 164 95 1531 367 5.4 1689 10,434 15,009 27.9 14.1
Mean 59 88 53 1134 254 3.0 956 5497 6113 22.1 7.0
SD 10 38 27 244 63 1.4 294 2159 1961 3.1 3.2

Organic soils (n = 16; γ = 5; α_m = 0.4)

Min - 180 10 593 201 1.0 132 2183 4320 5.6 1.8
Max - 484 41 1331 614 3.2 1393 12,245 9421 20.1 5.9
Mean - 275 19 879 336 1.6 660 6148 6989 14.3 3.4
SD - 88 9 189 119 0.6 337 2956 1183 4.4 0.9
Min⁴ 0 3 8 496 122 0.4 217 270 560 9.3 0
Max⁴ 95 80 640 2424 844 48 1457 37,638 19,992 88 93.3
Min¹ - 147 2 1 9 0.3 24 106 207 3.3 0
Max¹ - 580 531 817 586 42 2233 8642 9397 104 100.3

³Reference [9] for mineral soils; ⁴Reference [10] for organic soils; SOC = soil organic carbon, DPS = Degree of P saturation Mehlich III (M-III) and oxalate (ox), Min = minimum, Max = maximum, SD = standard deviation.
### Table 3. Mineralization of organic N during the 100-d incubation period simulated by a zero-order kinetics model.

<table>
<thead>
<tr>
<th>Soil⁠</th>
<th>Rep</th>
<th>Mineralized N (mg N·kg⁻¹) by period (d)</th>
<th>Mineralized N after 100 d</th>
<th>k</th>
<th>r²</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mg N·kg⁻¹</td>
<td>% total N</td>
<td>kg N·ha⁻¹</td>
<td>mg N·kg⁻¹·d⁻¹</td>
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<tr>
<td>MS</td>
<td>2</td>
<td>24 22 32 39 34 37 61 53</td>
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<td>47</td>
<td>3.6</td>
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<tr>
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<td>1</td>
<td>5 10 15 24 23 27 36 52</td>
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<tr>
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<tr>
<td>CH</td>
<td>2</td>
<td>14 26 31 46 45 68 84 92 78</td>
<td>78</td>
<td>85</td>
<td>0.8</td>
</tr>
<tr>
<td>VEs</td>
<td>1</td>
<td>18 35 49 74 82 110 160 181 163</td>
<td>163</td>
<td>160</td>
<td>1.5</td>
</tr>
<tr>
<td>VEs</td>
<td>2</td>
<td>18 36 54 85 79 110 159 175 157</td>
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</tr>
<tr>
<td>VEd</td>
<td>1</td>
<td>38 71 84 136 167 231 290 408 370</td>
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<tr>
<td>VEd</td>
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<td>35 61 78 201 176 244 313 346 310</td>
<td>310</td>
<td>340</td>
<td>2.1</td>
</tr>
</tbody>
</table>

¹See text for full names of soil series, ²Average of replicates 1 and 2. Rep = replicate, k = N mineralization rate. Mineral (top), mucky mineral (middle), and organic soils (bottom) separated by horizontal lines.

mucky clayey soils and between 0.84 and 3.40 mg N·kg⁻¹·d⁻¹ in organic soils, compared to the range between −0.16 and 1.91 mg N·kg⁻¹·d⁻¹ measured in organic soils [7]. The potential for N mineralization was high in VEd because minerotrophic peat materials have considerable nitrate release capacity [32]. As shown in Figure 1, mucky clayey soils behave similarly to organic soil materials. Mineral soils showed lower N mineralization rates.

On the other hand, on a per ha basis, mineral N production rate was in the range of 1.21 to 2.80 kg N·ha⁻¹·d⁻¹ (Table 3) after accounting for thickness and soil bulk density of the arable layer (Table 1). Compared to sandy soils (MS and AS), clayey soils (UB, RO, and PV), mucky clayey soils (LP and VEp) and organic soils (CH, VEs, and VEd) showed substantial N release capacity. By comparison, Canadian meadow soils released 0.5 - 1.3 kg N·ha⁻¹·d⁻¹ during 56 weeks of incubation at 25°C [6] and Canadian organic soils released 0.1 - 2.4 kg N·ha⁻¹·d⁻¹ during 34 weeks of incubation at 25°C [7].

### 3.3. Degree of Phosphate Saturation

As expected, the relationship between Pw and the (P/[Al + γFe])M-III percentage (Equation (3)) in mineral soils was texture-dependent [9] (Figure 2(a)). Indeed, the sandy soils required more P saturation to release the same amount of P as mucky clayey and clayey soils. Using γ = 1 for clayey soils and γ = 3 for mucky clayey soils, the distribution of points was similar. The γ factor of 3 inflating extracted Fe was closed to γ = 5 for the associated organic soils [10]. Obviously, the effect of organic matter
Figure 1. Aitchison distance of N mineralization rates in 10 soil series and variants from deep Verchères (VEd) minerotrophic (fen) peat.

Figure 2. Cate-Nelson partitioning of the relationship between degree of P saturation using the Mehlich-III method ($DPS_{MIII}$) (Equation (3)) and water extractable P ($P_w$) \cite{18} using $\gamma = 1$ for mineral soils, $\gamma = 3$ for mucky mineral soils and $\gamma = 5$ for organic soils. Mucky mineral soils behave like clayey mineral soils (a) and organic soils (b). Critical $DPS_{MIII}$ value of mucky mineral soils for environmental risk from subsurface drainage is 4.5%. TP = true positive (well classified problem soil); TN = true negative (well classified healthy soil); FP = false positive (misclassified problem soil: type I error); FN = false negative (misclassified healthy soil: type II error).

content on the relationship in Figure 2(a) was greater compared to soil texture.

Organic soils ($\gamma = 5$) were all below the critical $DPS_{MIII}$ value of 5\% (Figure 2(b)) proposed by \cite{10} to minimize water pollution through subsurface drainage. Using $\gamma = 3$ for mucky clayey soils, the Cate-Nelson part-
titioning procedure correctly classified the points in the diagram at about $P_w = 9.7 \text{ mg L}^{-1}$ on the x axis and 4.5% on the y axis. There was just one false positive observation. Indeed, mucky clayey soils accumulated organic matter and Fe under conditions of poor drainage similar to those prevailing during the genesis of the associated organic soils [10].

4. Conclusion

In this paper, we showed that mucky clayey soils have the potential to release mineral nitrogen in amounts similar to organic soils. On the other hand, it appeared that the degree of P saturation of mucky clayey soils could be modeled using the DPSM-III formulation (Equation (3)) with $\gamma = 3$ for mineral soils and $\gamma = 5$ for organic soils. A critical value of 4.5% could minimize P loss through subsurface drainage in mucky clayey soils. Mucky clayey soils could thus be managed similarly to organic soils for N and using DPSM-III with $\gamma = 3$ for P.

5. Acknowledgements

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