Nutrients Dynamics in Peat Soil: Influence of Fluctuating Water Table

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Abstract. This study assesses the dynamics of nutrients in peat soil under fluctuating water table using designated soil columns. Results showed that the concentration of total N and mineral-N (NO3--N and NH4+--N) were maximized when the water table was maintained at 40 cm. When the water table was fluctuated between 0-40 cm depth (representing the water table during wet season), soil available P reached its highest concentration in the soil. The fluctuation of water table between 40 - 80 cm depth (representing the water table during dry season) allows the gradual release of exchangeable K, Ca, Mg and Na. The study indicated that the fluctuating water table affects the different nutrients differently.

Keywords: Nutrients, Dynamics, Peat, Fluctuating, Water Table

1. Introduction
Continuous shifting of aerobic and anaerobic condition due to fluctuating water table could lead to biogeochemical changes of the soil that could affect the cycling of nutrients in the peat soil system. Understanding such changes on the nutrient dynamics will help in the management and the agronomic practices of crops planted on peat soil. The objective of this study is to evaluate the dynamics of nutrients in peat soils under fluctuating water table. It is hypothesized that the dynamics of nutrients were varied depending on the aerobic and anaerobic environment created by fluctuating water table.

2. Research Methodology
2.1 Field Sampling
A deep peat soil profile was taken from undisturbed natural peat soils in Klang, Selangor (2°57’42.99” N, 101°30’24.20” E). The soil samples were repacked into 9 designated acrylic soil columns measuring 20 cm by diameter and 100 cm by tall. The design of the column is as illustrated in Appendix 1.

2.2 Treatments
Each of the columns was applied with 14g of Baja Campuran Nanas (BCN) consisting of ammonium sulphate (AS), Christmas Island Rock Phosphate (CIRP) and Muriate of Potash (MOP) at the ratio of 72:1:27g/100g. Three treatments of water table were established in this experiment; (i) water table fixed at 40 cm, (ii) water table fluctuated at 0-40 cm and (iii) water table fluctuated at 40-80 cm.
2.3 Sampling
Soil samples and leachate were taken 3 weeks after fertilizer application to ensure uniform distribution and dissolution, followed by week 5 and week 8. The soil samples collected were oven dried, pulverized, sieved and analysed.

2.4 Sample and Data Analysis
The analysis was carried out at the Soil Science laboratory at the Forest Research Institute Malaysia (FRIM), Kuala Lumpur. The effects of treatments on soil parameter were tested using ANOVA. The means were compared using Tukey post-hoc test at 5% level. Then, the correlation was tested using Pearson correlation test.

3. Results and Discussions
Table 1 shows the descriptive data and ANOVA of soil chemical properties for each treatment whereas Table 2 shows the concentration of nutrients in leachate samples. Table 3 demonstrates the correlation between variables.

Shifting of aerobic and anaerobic condition through continuous saturation, drying and rewetting, following water table fluctuation in peat profiles had influenced the distribution and concentration of N, P and K along the vertical peat profile. In this study, soil samples of treated soil columns were acidic, with a pH of less than pH 4.1. Highly acidic features of peat is well expected because the soil is abundance with H+ ion and other organic acids such as humic acids and fulvic acids, resulted from decomposition process [1]. It is anticipated that low concentration of major nutrients, especially N and exchangeable bases (K, Ca, Mg and Na) was attributed to acidic environment in peat profile (pH < 4) and was common in tropical lowland forests [2]. Improvement of pH in deeper layers is due to deposition of observable concentration of exchangeable bases, especially Ca and Mg.

More than 50% of total carbon was present in the form of organic C, believed to be stored in organic material. Organic C in this study ranged between 15% – 54%, which was in the range of 12% - 60% for oligotrophic peat [3]. In the column with fluctuating water table, the C content tend to fluctuate as well. This was in line with findings by many which verify that anaerobic condition allows for carbon sinks whereas shifting into aerobic condition enhance the carbon to be oxidized and become sources for CO2 [1][4][5].

For all treated soil columns, the amount of N identified was ranged between 0.1% - 1.5%. This value is in the bottom range for oligotrophic peat (1% - 4 %) [3]. With ammonium sulphate application, the amount of N identified in this study appears to be minimum. Quantification of N indicated that almost 50% of N was in unknown form, suggested to be organic N since it was prominent in peat soils [1]. Smaller amount of N was found on the upper layer compare to deeper peat, indicating continuous decomposition process as well as mineralization of fertilizers in former layer. This is supported by significant amount of mineralized-N (in the form of NH4+-N and NO3--N) detected on the surface peat. There was a consistent release of NH4+-N especially by columns that exhibit permanent aerobic condition at 0-40 cm depth (T0 and T2). Under this condition, the key players of N-cycle; the microbes; are at their optimum condition to mineralize the organic material and fertilizers into NH4+-N and the nitrifiers subsequently oxidize NH4+-N into NO3--N. The process continued with reducing of nitrate into nitrogenous gaseous compounds by denitrifiers [6][7]. In this study, small amount of NO3--N was traceable at 0-20 cm peat layers for T0 and T2, demonstrating the sensitivity of nitrate with oxidizing condition. Apart from that, there was a possibility of dissimilar nitrate reduction to ammonium (DNRA), demonstrate by substantial amount of NH4+-N coupled with traceable NO3--N in anaerobic peat, high C/ NO3--N ratio, followed by significant correlation between both parameters. Even though these factors may indicate DNRA process [8], further study is needed to confirm the process of DNRA in peat soil. A study has reported that after fertilization, approximately 50% of N was assimilated by
crops whereas the remainder was leached primarily as NO3- [9]. In this study, high concentration of N was leached in T1, where the water table was fluctuated between 0-40 cm compared to the better drained surface peat, as in T0 and T2. This could be due to either soluble N release from fertilizers or the organic materials [10] since assimilation by crop was absent. Hence, the treatment which represented the wet season suggested that continuous fluctuating water table on peat surface coupled with high amount of precipitation could possibly enhance leaching of N from peat system. Concentration of available P was considerably high (approximately 1.5% - 8%) for all treated column, compared to those in natural peat which have a range of 0.04% - 0.5% [3]. The difference of about 6% is possibly contributed by CIRP fertilizer application in this study. The dynamics of P in treated soil column contrarily differs from N. Under fixed water table (T0), the amount of available P steadily decreased whereas in a column where water table was fluctuated between 40 – 80 cm depth (T2), the amount of P slowly increased throughout the study period. Highest concentration of available P was achieved when the water table fluctuated within 0 - 40 cm (T1) even though the pattern was inconsistent and concurrent with fluctuating water table. This is suggested due to variation of anaerobic soil conditions and reduction of Fe3+ compounds which advance P-mobilization in peat [11], and demonstrated by significant leached of Fe in the treated column. Observable amount of P detected on surface peat (0-20 cm) was possibly from the mineralization of CIRP fertilizer, even though other factors such as reduction of Fe3+ and desorption of phosphates [12] may occur.

**Table 1. Descriptive Data and ANOVA of Soil Chemical Properties**

| Soil Properties | Fraction | Treatment | Mean | Std. Deviation | Min. | Max. | F | Sig. |
|----------------|----------|-----------|------|----------------|------|------|---|-----|
| Nitrogen       | Total N  | T0        | 0.92 | 0.32           | 0.17 | 1.48 | 0.393 | 0.677 |
|                |          | T1        | 0.81 | 0.42           | 0.14 | 1.16 | 0.75  | 0.478 |
|                |          | T2        | 0.82 | 0.42           | 0.16 | 1.43 | 0.416 | 0.662 |
|                | NH4+     | T0        | 1396.83 | 2541.558 | 87.75 | 6767.27 | 0.575 | 0.478 |
|                |          | T1        | 822.375 | 489.9849 | 57.94 | 1414.88 | 0.75  | 0.478 |
|                |          | T2        | 704.097 | 1238.777 | 36.03 | 3608.96 |       |      |
|                | NO3-     | T0        | 4.88 | 14.32064      | 0    | 55.31 | 0.416 | 0.662 |
|                |          | T1        | 1.65 | 4.34699       | 0    | 12.36 |       |      |
|                |          | T2        | 3.29 | 7.57755       | 0    | 25.51 |       |      |
| Available P    |          | T0        | 39.37 | 15.31       | 18.18 | 68.68 | 3.34  | 0.045 |
|                |          | T1        | 47.42 | 21.70       | 15.22 | 79.53 | 0.237 | 0.790 |
| pH             |          | T2        | 31.23 | 13.35       | 14.90 | 54.34 |       |      |
|                |          | T0        | 3.75  | 0.20          | 3.37  | 4.05  |       |      |
|                |          | T1        | 3.70  | 0.13          | 3.58  | 4.00  | 0.237 | 0.790 |
|                |          | T2        | 3.74  | 0.21          | 3.37  | 4.07  |       |      |
| Carbon         | Total C  | T0        | 47.68 | 22.00       | 5.82  | 66.26 | 0.035 | 0.966 |
|                |          | T1        | 48.49 | 23.27       | 6.10  | 71.56 |       |      |
|                |          | T2        | 46.32 | 23.29       | 7.28  | 72.02 |       |      |
| Organic Carbon |          | T0        | 35.85 | 16.54       | 4.37  | 49.82 | 0.035 | 0.966 |
|                |          | T1        | 36.46 | 17.50       | 4.59  | 53.81 |       |      |
|                |          | T2        | 34.82 | 17.51       | 5.47  | 54.15 |       |      |
| Exchangeable K | Soil     | T0        | 0.85  | 0.09         | 0.67  | 0.96  | 22.365 | 0.000 |
| Bases         |          | T1        | 1.12  | 0.17         | 0.76  | 1.26  |       |      |
|                |          | T2        | 0.83  | 0.13         | 0.62  | 1.10  |       |      |
|               | Soil     | T0        | 2.97  | 1.28         | 1.46  | 5.48  | 0.357  | 0.702 |
| Exch. K       |          | T1        | 3.15  | 1.23         | 1.46  | 5.49  |       |      |
|                |          | T2        | 3.34  | 1.09         | 1.97  | 5.27  |       |      |
|               | Soil     | T0        | 7.55  | 5.43         | 3.63  | 19.9  | 0.369  | 0.694 |
| Exch. Ca      |          | T1        | 8.27  | 5.91         | 3.32  | 20.9  |       |      |
|                |          | T2        | 9.35  | 5.96         | 3.15  | 21.7  |       |      |
i) T0 = Water table fixed at 40 cm; T1 = Water table fluctuated between 0-40 cm; T2 = Water table fluctuated between 40-80 cm

Table 2. Concentration of Nutrients in Leachate Sample

| Nutrients (mg/L) | W3          | W5          |
|------------------|-------------|-------------|
|                  | D1 | D2 | D3 | D4 | D5 | D1 | D2 | D3 | D4 | D5 | D1 | D2 | D3 | D4 | D5 | D1 | D2 | D3 | D4 | D5 |
| N                | -  | -  | 7.85 | 23.96 | 6.31 | -  | -  | 8.51 | 6.67 | 2.44 | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| P                | -  | -  | 3.09 | 0.16 | 0.59 | -  | -  | 0.87 | 0.17 | n.d. | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| K                | -  | -  | 14.95 | 22.78 | 15.43 | -  | -  | 16.07 | 21.74 | 11.87 | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Ca               | -  | -  | 7.46 | 12.36 | 9.84 | -  | -  | 7.67 | 27.74 | 37.91 | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |
| Mg               | -  | -  | 10.73 | 17.30 | 14.56 | -  | -  | 12.00 | 63.11 | 22.25 | -  | -  | -  | -  | -  | -  | -  | -  | -  | -  |

Notes:

Table 3. Correlation between Variables

| Variables | pH | Organic C | NH₄⁺ | Avail. P | Exch. Ca | Exch. Mg | Exch. Na |
|-----------|----|-----------|------|----------|----------|----------|----------|
| NH₄⁺      | -0.682** | .348* | -    | -        | -        | -        | -        |
| NO₃⁻      | -0.507** | - .711** | - | -        | -        | -        | -        |
| Avail. P  | - .564** | .490** | -    | -        | -        | -        | -        |
| Exch. K   | - .307*  | - .446** | -    | -        | -        | -        | -        |
| Exch. Ca  | - .717** | -    | -    | -        | -        | -        | -        |
| Exch. Mg  | - .946** | - .355* | - .536** | .814** | -        | -        | -        |
| Exch. Na  | - .509** | - .344* | .481** | .528** | -        | -        | -        |
| Soil CEC  | .823**  | .534** | -.652** | -.854** | -.366*  | -        | -        |

Notes: i) **Correlation is significant at the 0.01 level (2-tailed); ii) *Correlation is significant at the 0.05 level (2-tailed)

Decrement of P in deeper peat layer as well as mineral soil underneath peat shows a possibility of P forming complexes, primarily with trivalent or bivalent cations such as Ca, Al and Fe which was
prevalent in acidic condition [13]. The former was confirmed in this study as demonstrated by increment of Ca in deeper layers whereas the latter was not determined in this study. The insignificant amount of P in the mineral soil layers could be due to P-fixation, which is expected in acidic environment and the fact that P which exist in the anion forms (PO4_2-) are repelled by negatively charge clay [14].

Low concentration of K in this study is suspected to be due to domination of acidic cation (H+ and Al3+), demonstrated by low soil pH, as well as K being readily leached in soil solution, due to its high mobility. The former confirmed by the significant relationship between pH and K whereas the later proven by the high amount of K leached from the column. Similar with P, highest exchangeable K was achieved when the water table fluctuated within 0-40 cm. However, this high K concentration leads to more K being leached from the system. Nevertheless, some amount of K was found to be deposited at different peat depth, showing sign of its high mobility in a peat profile. Even though it was previously reported that two cations; H and Ca occupied most exchange sites in peat soils [3], the amount of Mg in this study was comparable with Ca, for all treatments. Since different cations were associated with different degrees of organic compounds, therefore the status of exchangeable cations in organic materials seems to be complicated to observed [3]. Hence, the dominance of Ca in peat agreed to be varied, depending on nature of the peat. Most Ca and Mg were observed when the Water table fluctuated between 40-80 cm depth (T2) which represented dry season, followed by T1 and T0. The movement of water through fluctuating water table is an important pathway for the elements to move up and down the peat profile. Even though the mobility and concentration was high in T2, the amount of leached Ca and Mg was high in T1 (water table fluctuated between 0-40 cm), which represented the wet season. Consequently, deposition of these bases in mineral soils underneath the peat can be utilized through fluctuating water table as most of them were highly mobile in soil solution. Hence, it is suggested that the high amount of exchangeable bases with minimum leaching was achieved when the water table fluctuated between 40 – 80 cm, near to the mineral soil layer.

Conclusions
Results showed that the fluctuating water table in peat soils exhibit different dynamics of N, P and K as well as chemical properties of the soils. By maintaining the water table at 40 cm level, the concentration of total N and mineral-N (NH4+ and NO3-) was maximized. When the water table was fluctuated at 0-40 cm depth (which is representing the water table during wet season), soil available P reached its highest concentration in the soil. The fluctuation of water table at 40-80 cm depth allows gradual release of exchangeable bases (K, Ca, Mg and Na) accompanied by less leaching. In view of the management practice, this study suggested that the planting, maintaining and harvesting of crop could follow the fluctuating of water table in peat. The fluctuation of this water table may be predicted through the monitoring of the precipitation pattern and may be divided into wet and dry season. Based on the results of this study, the planting could be done before the wet season where the mineral N was highly available. The months following wet season will gradually release soil-P which will further boost the crop growth. The dry season may help in the fruiting stage of the crop through gradual release of exchangeable K as well as other bases which is important for fruit development. Even though the activity in the field can be predicted through this seasonal variation, however, it must be accompanied by good agronomic practices such as the fertilization and liming activities.

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