Quantification of Soil N, P and K Balance In Peat Soils: Influence of Fluctuating Water Table

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Abstract. This study intends to develop the soil N, P and K balance in peat soils by quantifying the input, internal flow and output of the nutrients under different water table conditions, with and without the pineapple crops uptake. The soil samples for each water table conditions were analyzed for total-N, mineral-N, available-P and exchangeable K. Results showed that pineapple of the variety Moris requires high input of N and K compare to P. Without crops uptake, all treatments indicate positive soil nutrient balance where the treatment with fluctuating water table between 40-80 cm depth showed highest positive balances. In contrast, negative nutrient balance occurred in the presence of uptake by pineapple, where treatment with fluctuating water table between 0-40 cm recorded the highest nutrient deficiency. It is suggested that fluctuating water table influence the soil nutrient dynamics and soil nutrient balance and in this case act as the main pathways of nutrient loss through leaching.

Keywords: nutrients, balance, peat, water table, fluctuating

1. Introduction
The deficiency of nutrients often leads to various problems in pineapple crops. For example, N deficiency resulted in small fruits and slow growth of the pineapple [1] while P-deficiency reduces the growth of entire pineapple parts [2]. In addition, the K-deficiency reduces the fruit size and produce fruits with low acidity and less aroma [3]. As pineapple is a crop that demands high plant nutrients, an efficient fertilizer management program is critical in pineapple farms [3]. The common method to verify the effectiveness of fertilization in the field is through the soil nutrient balance approach. The soil nutrient balance quantifies the differences between soil nutrient input and soil nutrient output so that the proficient nutrient balance can be achieved [4][5]. In this study, a small fraction of soil nutrient balance was observed. The objective of this study is to quantify the input, internal flows and output as well as to develop the nutrient balance of peat system under different water table conditions with and without the pineapple crops uptake. Modified slightly from the nutrient balance which was previously implemented by Food and Agriculture Organization of the United Nations (FAO) [6], this study taken into account the role of fluctuating water table in the unique peat system.
2. Materials and Methods

2.1. Soil column settings
A peat profile from the field was repacked into 9 designated acrylic soil columns measuring 20 cm by diameter and 100 cm by tall. A slit was constructed at 20 cm intervals to withdraw leachate sample and was controlled by a copper valve (Appendix 1). Each of the columns was applied with ammonium sulphate (AS), Christmas Island Rock Phosphate (CIRP) and Muriate of Potash (MOP) at the ratio of 72:1:27g/100g, following the recommendation of Baja Campuran Nanas (BCN) by Malaysia Pineapple Industry Board (MPIB). 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 with three replications for each treatment. The water table is maintained by using a tap screw at each column. The experiment was conducted for 8 weeks and destructive sampling was carried out at the end of 8 weeks to collect soil samples and soil leachate.

2.2. Determination of soil N, P and K content
The soil samples collected were oven dried, pulverized, sieved and analysed. The analysis was carried out at the Soil Science laboratory at the Forest Research Institute Malaysia (FRIM), Kuala Lumpur. Exchangeable bases (K, Ca, Mg and Na) were determined by using ammonium acetate method [7] and were analyzed using Atomic Absorption Spectrophotometer (AAS) Perkin Elmer Analyst 300 [7]. Total N was analyzed using CNS autoanalyzer, soil ammonium-N (NH$_4^+$-N) and nitrate-N (NO$_3^-$-N) were analyzed using steam-distillation method [8], whereas available P was determined using Aqua Regia and Blue method [9]. 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.

2.3. Nutrient input
The main input considered was mineral fertilizer in the form of Ammonium Sulphate (AS), Christmas Island Rock Phosphate (CIRP) and Muriate of Potash (MOP) which were listed by Malaysian Pineapple Industry Board (MPIB) as standard fertilizer of Baja Campura Nanas (BCN) required by pineapple crops planted in peat soils. The ratio of fertilizer applied was 72:1:27 (AS: CIRP: MOP) with 14g of the mixture applied per pineapple and was represented by each column.

2.4. Internal flow of nutrients
Internal flow is considered as the concentration of nutrient retained/stored and calculated as concentration of N, P and K contained in soil column. The first part calculates the amount of nutrient according to five soil depth (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm) in a peat profile and the second part quantify solely the layer beyond roots zone. The data was then compared between the presence and absence of pineapple crop uptake.

2.5. Nutrients output
In this study, the soil leachates flowed from the soil column tubes was collected and considered as the nutrient output. The first part calculated the amount of leached nutrient at different depths of column whereas the later parts solely measured the 0-20 cm depth, representing the reachable zone of pineapple roots.

2.6. Nutrients balance
The nutrient balance was calculated using the following Equation 1 [6]:

\[ \text{Nutrient balance} = \text{Soil total input} - \text{Soil total output} \]  
(Equation 1)
2.7. **Nutrients content in pineapple**

The pineapple crops in this study were not directly sown in the soil column. The crops were taken from the studied fields where all the field research data was obtained. Nutrient content in different parts of pineapple crops variety Moris were analyzed. The pineapple crops were divided into six main parts namely the leaves, fruits, roots, peduncles, stems and crowns. The parts were divided according to the previous study conducted on pineapple crops [10]. The parts were analyzed for N, P, K, Ca, Mg, Fe, Mn, Cu, Zn and B. The analysis was conducted at Department of Agriculture (Soil and Plant Analytical Laboratory), Kuala Lumpur.

### 3. Results and Discussions

3.1. **Soil nutrient input**

Recommended fertilizer input for pineapple is 14 g/plant with a ratio of 72:1:27 per100 gram. Based on this recommended rate, Table 1 demonstrate the conversion amount of nutrient input in mg/plant to the soil through fertilizer application.

#### Table 1: Soil Input Fertilizer

| Nutrient | T0 (Water table fixed at 40 cm) | T1 (Water table fluctuate at 0-40 cm) | T2 (Water table fluctuate at 40-80 cm) |
|----------|-------------------------------|-----------------------------------|-----------------------------------|
| N        | 10080                         | 10080                             | 10080                             |
| P        | 140                           | 140                               | 140                               |
| K        | 3780                          | 3780                              | 3780                              |

Based on the amount of soil input, it is noticeable that the fertilizer ratio significantly differed for N, P and K. Highest concentration of N was required by the crop, followed by K and P. This is due to N and K preference by pineapple [1]. N was stored mostly in pineapple’s leaves, stem and crown whereas K was observable in pineapple crown, peduncle and fruit (Table 4). Other nutrients namely Ca and Mg was highly demanded by pineapple crops where they are stored mostly in its stem and leaves [3].

3.2. **Soil stored nutrient**

Table 2 shows the amount of stored nutrient for each column at different depths in different water table conditions.

#### Table 2: Stored Nutrient at Different Depths for Treated Columns

| Nutrient                  | Soil depth | Treatment T0 (Water table fixed at 40 cm) | T1 (Water table fluctuate at 0-40 cm) | T2 (Water table fluctuate at 40-80 cm) |
|---------------------------|------------|------------------------------------------|--------------------------------------|---------------------------------------|
| Total N                   | D1         | 8553.33                                  | 1586.67                              | 5850                                  |
|                           | D2         | 9416.67                                  | 10716.67                             | 11426.67                              |
|                           | D3         | 9426.67                                  | 11016.67                             | 9690                                  |
|                           | D4         | 9393.33                                  | 11200                                 | 9330                                  |
|                           | D5         | 9346.67                                  | 5893.33                              | 4656.67                               |
| NH₄⁺ (Ammonium-N)         | D1         | 6296.84                                  | 1243.37                              | 3069.86                               |
|                           | D2         | 233.26                                   | 1136.72                              | 140.34                                |
|                           | D3         | 179.49                                   | 1092.01                              | 117.26                                |

Internal flow of stored nutrient (mg/kg)
The amount of total N was fractioned into organic-N and mineral-N ($\text{NH}_4^+$ and $\text{NO}_3^-$). The calculation of stored nutrient was represented in Appendix 2. The amount of stored nutrient was slightly differed between treatments. For total N, T0 (water table was fixed at 40 cm depth) resulted in the highest storage followed by T2 (water table fluctuated between 40 – 80 cm depth). Both treatments have an aerobic soil condition on 0-40 cm depth. The treatment with fluctuating water table of 0-40 cm (T1) shows lower stored-N. This shows that by maintaining the water table at 40 cm depth, the aerobic condition allows the peat to mineralize into $\text{NH}_4^+$-N and $\text{NO}_3^-$-N, much higher than those in fluctuating water table treatment.

### 3.3. Soil nutrient output

Table 3 indicates the average amount of nutrient leached from soil column at different depths for different water table conditions, which was considered as soil nutrient output.

#### Table 3: Nutrient Output at Different Depths for Treated Soil Columns

| Soil depth | T0 (Water table fixed at 40 cm) | T1 (Water table fluctuate at 0-40 cm) | T2 (Water table fluctuate at 40-80 cm) |
|------------|---------------------------------|--------------------------------------|--------------------------------------|
| Output (Leaching) in mg/L | D1 | 0.00 | 154.03 | 0.00 |
| | D2 | 0.00 | 146.03 | 0.00 |
| | D3 | 8.53 | 135.80 | 4.56 |
| | D4 | 13.14 | 89.01 | 4.55 |
| | D5 | 3.91 | 6.27 | 1.94 |
| Total | 25.58 | 531.14 | 11.05 |
| P | D1 | 0.00 | 4.72 | 0.00 |
Notes:
i) 1 mgL⁻¹ = 1 mgkg⁻¹

ii) Nutrient output use in the table is the mean of nutrient for week 3, week 5 and week 8 which was calculated based on raw data in Appendix 3

### 3.4. Nutrient uptake by pineapple

Table 4 showed the nutrient status in different components of pineapple crop, namely pineapple leave, fruit, root, peduncle, stem and crown.

| Sample  | N | P | K | Ca | Mg | Fe | Mn | Cu | Zn | B |
|---------|---|---|---|----|----|----|----|----|----|---|
| Leaves  | 2.11 | 0.09 | 0.36 | 0.24 | 0.43 | 80 | 162 | 2 | 29 | 7 |
| Fruit   | 0.92 | 0.09 | 0.80 | 0.05 | 0.16 | 34 | 19 | 1 | 22 | 4 |
| Root    | 0.53 | 0.05 | 0.14 | 0.10 | 0.15 | 119 | 29 | 1 | 10 | 2 |
| Peduncle| 0.88 | 0.06 | 1.35 | 0.11 | 0.20 | 38 | 38 | 1 | 13 | 3 |
| Stem    | 1.76 | 0.09 | 0.41 | 0.49 | 0.73 | 61 | 37 | 3 | 26 | 4 |
| Crown   | 1.38 | 0.22 | 1.69 | 0.10 | 0.20 | 38 | 99 | 2 | 18 | 7 |

The examined properties were exclusively for pineapple variety Moris. From the results, pineapple take up more N and K followed by Mg and Ca, and P. From the data, the pineapple variety Moris nutrient uptake follows the order of N > K > Mg > Ca > P for macronutrients and Mn > Zn > B > Cu for the micronutrients. Previous research showed that the different soil type and pineapple variety may result in different order of nutrient uptake [3].

### 3.5. Nutrient balance without pineapple-nutrient uptake

Table 5 display the nutrient balance without crop uptake in peat system.

| Nutrient | Soil depth | T0 (Water table fixed at 40 cm) | T1 (Water table fluctuate at 0-40 cm) | T2 (Water table fluctuate at 40-80 cm) |
|----------|------------|---------------------------------|---------------------------------------|---------------------------------------|
| Soi Nutrient Input(a) (mg) | N | 10080 | 10080 | 10080 |
| P | 140 | 140 | 140 |
| K | 3780 | 3780 | 3780 |
| Soil Nutrient Output(b) (mg) | N | D1 | 0.00 | 154.03 | 0.00 |
| D2 | 0.00 | 146.03 | 0.00 |
From Table 5, the results showed that soil was positively balanced with some additional nutrients from the soils.

### 3.6. Nutrient balance with pineapple-nutrient uptake

Table 6 shows the soil nutrient balance in peat system in the presence of pineapple crops. The data indicate that the soil was negatively balanced after uptake by the pineapple crop.

| Nutrient | Soil depth | T0 (Water table fixed at 40 cm) | T1 (Water table fluctuate at 0-40 cm) | T2 (Water table fluctuate at 40-80 cm) |
|----------|------------|--------------------------------|-------------------------------------|-------------------------------------|
|          |            | N          | P          | K          | N          | P          | K          |
|          |            | 10080      | 140        | 3780       | 10080      | 140        | 3780       | 10080      | 140        | 3780       |

Soil Nutrient Input (mg) ^c

Soil Nutrient Output Through Leaching (mg) ^b

Soil Nutrient Output Through Crops Uptake (mg) ^c

Leaves 21100 21100 21100
Fruit 9200 9200 9200
Root 5300 5300 5300
Peduncle 8800 8800 8800
Stem 17600 17600 17600
Crown 13800 13800 13800

N 75800 75800 75800

Leaves 900 900 900

\* Soil nutrient balance = a - b

From Table 5, the results showed that soil was positively balanced with some additional nutrients from the soils.
### Table 1: Nutrient Concentration in Different Parts of the Plant

| Part     | Nutrient | Concentration |
|----------|----------|---------------|
| Fruit    | N        | 900           |
| Root     | P        | 500           |
| Peduncle | K        | 600           |
| Stem     |          | 900           |
| Crown    |          | 2200          |

| Part     | Nutrient | Concentration |
|----------|----------|---------------|
| Leaves   | N        | 3600          |
| Fruit    | P        | 8000          |
| Root     | K        | 1400          |
| Peduncle |          | 13500         |
| Stem     |          | 4100          |
| Crown    |          | 16900         |

| Nutrient | Soil Nutrient Balance* |
|----------|------------------------|
| N        | -65720                 |
| P        | -5860                  |
| K        | -43720                 |

* Soil nutrient balance = a – (b + c)

In this study, the stored nutrients show higher total N and mineral N (NH\(_4^+\)-N and NO\(_3^-\)-N) concentration when the water table was fixed at 40 cm depth compare to other treatments. Highest concentration was detected at 20 - 40 cm depth, where the peat was in contact with water. This is understood since exposure of new material for decomposition lead to increment of mineral N (NH\(_4^+\)-N and NO\(_3^-\)-N) [11][12][13]. Aerobic condition in 0-40 cm layer conceivably enhance fermentation of newly exposed carbohydrates as well as degradation of acid through hydrolysis and enzymatic activity whereas the anaerobic condition allow the acid to stabilized, as reported in sphagnum peat [14]. However, the rate differed according to types of vegetation and local climate condition especially in tropical lowland forest [12]. The soil output pathway considered in this study was through leaching. It is considered as ‘difficult flow’ in nutrient balance [6]. As shown in Table 3, highest N, P and K loss occurred when the water table fluctuates between 0-40 cm depths. The treatment which represents wet season enlightened the roles of water table in the movement of dissolved nutrients outside peat system. The soil nutrient balances for different water table treatments demonstrate a positive balance for all treatments in the absence of nutrient uptake. The highest positive balance of N, P and K were achieved by the treatment with fluctuating water table between 40-80 cm, possibly due to the constant exposure to aerobic condition which helps in rapid decomposition and mineralization [4][15]. The lowest positive balance of N, P and K was recorded by treatment with water table fluctuated between 0-40 cm which represents the wet season, due to high leaching. In the presence of uptake by crops, the result was contrasting where all the treatments signify a negative nutrient balance. This is an indication of the insufficient amount of nutrients available for crops uptake. The condition was worsened when the water table was fluctuated between 0-40 cm depths, indicating nutrients were in short supply upon wet season, believed to be loss through leaching. In the N- and P-rich peat, a study reveals that amount of dissolve N and P in peat water was influenced by biogeochemical process, uptake and lateral transport process [16]. This showed that apart from dissolving of N and P in peat water, much of these nutrients loss through leaching as proven in this study. Hence, it is believed that fluctuating water table influences the soil nutrient balance by enhancing nutrient leaching.

### 4. Conclusions

This study suggested that the fluctuating water table in peat soils has resulted in negative soil nutrient balance and contribute towards the shortage of nutrients supply for pineapple crops. Even with the
recommended fertilizer application, most of the major nutrients were loss through leaching. In view of the management practice, it is suggested that the fluctuating of water table should be closely monitored due to different nutrient dynamics occurred under different water table conditions. It is recommended that a continuous monitoring of water table in a peat soils may help in predicting the dynamics of nutrient as well as the soil chemistry in future.

5. Acknowledgement
The authors gratefully acknowledge financial support (Excellence Fund) from Universiti Teknologi MARA (UiTM).

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APPENDIX 1
Design of the Soil Column

APPENDIX 2
Stored Nutrients at Different Depths for Treated Columns
a) Nitrogen (Total N, organic-N and mineral-N)

\[
1\% = 10000 \text{ mg/kg}
\]

Therefore, Concentration of N in mg/kg

\[
= \frac{\text{Amount of N}}{\text{NH}_4^+ + \text{NO}_3^-} \times 10000 \text{ mg/kg}
\]

b) Exchangeable K

To convert the unit cmol/kg into mg/kg, the concentration of exchangeable K was multiplied with 390 after taking account of the valences and atomic weights of K cation.

\[
\begin{align*}
\text{Exchangeable K} & = 0.85 \times 390 = 331.5 \\
& = 1.23 \times 390 = 479.7 \\
& = 0.83 \times 390 = 323.7
\end{align*}
\]

Total K

\[
1661.4 \quad 2191.8 \quad 1626.3
\]

**Notes: No conversion was made to concentration of P as they were already given in mg/kg.

APPENDIX 3
Concentration of Nutrients in Leachate Sample

| Week | N (mg/L) | P (mg/L) | K (mg/L) | Ca (mg/L) | Mg (mg/L) |
|------|----------|----------|----------|-----------|-----------|
| D1   | 0.85x390=331.5 | 1.22x390=475.8 | 1.01x390=393.9 |
| D2   | 0.85x390=331.5 | 1.23x390=479.7 | 0.83x390=323.7 |
| D3   | 0.91x390=354.9 | 1.20x390=468 | 0.69x390=269.1 |
| D4   | 0.76x390=296.4 | 1.12x390=436.8 | 0.76x390=296.4 |
| D5   | 0.89x390=347.1 | 0.85x390=331.5 | 0.88x390=343.2 |

Notes:

- No conversion was made to concentration of P as they were already given in mg/kg.