Vertical Distribution of Macro Nutrient on Drained Peat for Acacia crassicarpa plantations

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Abstract. The development of peatlands for pulp Industrial Timber Estates (ITE) by reducing the water table has changed the balance of the ecosystem and the characteristics of peat soil in the area. The research aims to determine soil chemical after the implementation of drainage system on peat for Acacia crassicarpa plantation. Two field researches were conducted in ITE and natural peatlands in Riau Province. The research plot was made in a single transect observations perpendicular to the drainage channel. Parameters observed were chemical characteristics including vertical distribution of macro nutrients. The characteristics condition of plantation forest was then compared with the natural peat site. The measurement result of chemical parameters analyzed descriptively in the form of charts. Simple regression is used to observe the effect of drainage on those characteristics. The results showed that the presence of drainage system gave significant changes in the level of peat maturity at 0-150 cm depth as it causes subsidence rate of 5.5 cm / year. Further, the chemical characteristics indicates that there is an increase in the value of the macro nutrient content of N, P, K, Ca in ITE, however, there is a deficit of K, especially at 50-100 cm depth.

1. Introduction
The peatland ecosystem is one of the types of wetland ecosystems that is formed from the accumulation of organic materials and generally occupies a basin between two large rivers. In Indonesia, its utilization has begun since approximately 1960s as agricultural lands for transmigration programs [1,2,3]. Since 1990s, government has developed peatlands for palm oil plantations and industrial timber estates (ITE), especially in Sumatera and Kalimantan, hence peat ecosystem possesses essential role in supplying raw materials for pulp and paper.

Peatlands utilization for ITE pulp commodities begins by creating drainage canals to increase oxygen availability for roots, so that plants can grow and develop properly [4]. The ITE pulp has entered the 5th rotation on average. The logging process at the end of the cycle, product transportation, land preparation for the upcoming planting season, fertilization and herbicide application are always maintained in each rotation period. Interruptions that might occur during the ITE management are the factors that can accelerate peatland degradation. Peatland degradation will affect the carrying capacity of peatlands and indirectly determine the existence of the pulp and paper industries, particularly pertaining the supply of raw materials from ITE’s pulp fields. This study aims to see the extent of the impact of land degradation caused by drainage problem on nutrient contents through its vertical distribution.

2. Method
2.1. Materials
This research carried out in ITE area of PT Arara Abadi, Rasau Kuning District, Siak Regency, Riau Province. The study was conducted in the wildlife sanctuary area of Pulau Besar Lake/Pulau Bawah Lake. The plots were placed on A. crassicarpa stands with age rotations of 1 year (Plots 442-01; 442-02, 443); 2 years (plots 441, 447-A, 447-B); 3 years (Plots 618, 619, 620) and 4 years (Plots 287-B, 288-B, 336-B).

2.2. Procedure
Determination of observation area and/or sampling of peat soil in each selected research location is attempted to represent the whole condition of the land [5]. Distribution of observation points in each location is plotted along a 100 m long transect that is made perpendicular to the drainage channel (tertiary canal). The first observation point was placed 20 m from the channel lips, with the distance of 50 m to the next points, so that there were 3 observation points or soil sampling within a transect representing the distance from the drainage channel. The transect line was placed on 12 locations of A. crassicarpa stands, therefore there were 36 observation points in total. Soil sampling were taken at each observation point.

Sampling of the peat soil carried out at each depth of 50 cm up to the limit of mineral soil horizon. Sampling of peat soil were conducted at each additional interval of 50 cm depth, weighing 1 kg each. The soil samples then analysed at the laboratory. Parameters of the soil chemical properties and the methods used are presented in Table 1.

| Soil Chemical Properties | Measurement Methods/Analysis | Classification/Correlation |
|--------------------------|------------------------------|-----------------------------|
| pH (H$_2$O)              | Glass electrode              | Peat fertility               |
| N                        | Kjeldahl                     | Peat fertility and maturity indicator |
| P                        | Bray I                       | Peat fertility indicator    |
| K                        | Wet sponging                 | Peat fertility indicator    |
| Ca                       | Wet sponging                 | Peat fertility indicator    |
| Mg                       | Wet sponging                 | Peat fertility indicator    |
| Ash content              | Dry sponging                 | Peat fertility indicator    |

Differences in pH, N, P, K, Ca, Mg, and ash values were vertically determined through diversity analysis. Correlations between nutrient content concentration and peat thickness were analysed using regression-correlation technique.

3. Result and discussion
Ash content and pH are important factors to identify peat soil fertility. The higher the ash content, the higher the mineral content; meaning that the peat soil is more fertile. The degree of soil acidity (pH) determines whether or not the nutrients are absorbed by plants, thus indirectly determining soil fertility. In general, nutrients are easily absorbed by plant roots under neutral soil pH because most of the nutrients are easily soluble in the water. On acid soils as in peat soil, P element can not be absorbed by plants because it is tied (fixated) by Al. In addition, peat soil fertility is also affected by the thickness of its layers and their maturity levels [6,7]. The average value of ash content and pH based on peat thickness in the study sites are presented in Table 2.

Based on Table 2 it is known that the average pH (H$_2$O) value at the ITE study sites is between 3.0-3.6, whereas in the natural peat forests (NF) it ranges from 3.5 to 4.2. Based on an assessment criteria of the soil chemical properties, peat soil at both sites reacted very acidic. In general, peat soils in Indonesia have a low pH of less than 4.0 [8], whereas the tropical peatlands generally have a very acidic reaction with a pH ranging from 3.0-4.5 [6].

The average pH in natural peat forest sites has higher value than in ITE sites. In drained peatlands such as in A. crassicarpa ITE, generally the soil becomes more acidic because huge amount of water
comes out of the peat layer so that the OH⁻ ions are reduced and the H⁺ ions are induced. The amount of OH⁻ ion in the soil is inversely proportional to the amount of H⁺[9].

Based on correlation analysis between peat depth and pH value in ITE sites, it did not show any significant difference. The soil pH values both in the ITE and natural peatland forests study sites showed an increasing trend after approaching mineral soil under the peat layer. Research done at the natural peat in Rokan Hilir (Riau) revealed the variation of pH in peat depth and peat thickness where a higher pH found in upper and lower layers and the lowest pH in the middle layer, particularly in the thick peat [10].

Table 2. The average value of pH and ash content based on peat thickness in the ITE and natural peat forest (NF).

| Peat Depth (cm) | pH H₂O | Ash Content (%) |
|----------------|--------|-----------------|
|                | ITE    | NF              |
| 0-50           | 3.3    | 3.5             | 2.3 | 2.9 |
| 50-100         | 3.3    | 3.5             | 1.3 | 2.5 |
| 100-150        | 3.3    | 3.6             | 1.6 | 2.0 |
| 150-200        | 3.1    | 3.7             | 1.3 | 2.3 |
| 200-250        | 3.3    | 3.7             | 3.2 | 2.6 |
| 250-300        | 3.4    | 3.7             | 1.9 | 3.3 |
| 300-350        | 3.3    | 3.8             | 3.6 | 3.0 |
| 350-400        | 3.2    | 3.9             | 5.2 | 4.7 |
| 400-450        | 3.0    | 4.0             | 1.2 | 4.3 |
| 450-500        | 3.3    | 4.0             | 1.2 | 3.2 |
| >500           | 3.6    | 4.2             | 1.4 | 3.8 |

Annotation: ITE: Industrial Timber Estates, aNF: Natural Forest

The results above are in line with Sallantaus [11] who classified the impact of drained peatlands on acidity levels: (1) On a thick peat with poor nutrients, the pH decreases after drainage process, (2) On peat surface with generally lower pH, pH increases close to mineral soil under the peat layer, particularly during the low runoff period, (3) On nutritious peat rich in sulfur or acid sulfuric soils, the pH significantly decreases during high runoff period after the dry season.

The value of ash content could serve as an indicator of peat soil fertility [12]. It is considered to have a high peat fertility rate (eutrophic) if the ash content reaches 10%; moderate (mesotrophic) for 5% ash content; and low (oligotrophic) if it possesses approximately 2% ash content. Ash content in the ITE study sites ranges from 1.2-5.2% while in natural peatland forests it ranges from 2.0-4.7%. Therefore, peat soil fertility rate in the study area considered as low (oligotrophic) to moderate (oligotrophic).

Peat fertility classified into three groups namely low, medium and high [13] (Table 3). Average value of pH, N-total, available-P and available-K in the study sites are presented in Table 4. The average pH value within the study area is low, providing lower P-available due to Al bound. N-total is considered to be high, but most of them are in unavailable form for the plants due to higher prevalence of C/N ratio on the peatlands.

Table 3. Assessment criteria of peat soil fertility level [13]

| Component      | Assessment Criteria |
|----------------|---------------------|
|                | Low     | Medium | High   |
| pH             | < 4.0   | 4.0-5.0| > 5.0  |
| N-total (%)    | < 0.2   | 0.2-0.5| > 0.5  |
| Available-P (ppm) | < 20   | 20.0-40.0| > 40  |
| Available-K (me/100) | < 0.39 | 0.39-0.78| > 0.78 |

Table 4. Average value of pH, N-total, available-P and available-K within IF and NF.
Fertility Status of Mineral Soil under the Peat Layer

The mineral soil under the peat soil layer in the study site lies at a depth that varies between 150 and 750 cm. Its appearance is presented in Figure 5.

Table 5. The chemical properties of mineral soil under the peat soil layer at PT. Arara Abadi, Rasau Kuning District.

| Component                      | ITE  | Criteria | NF  | Criteria |
|--------------------------------|------|----------|-----|----------|
| pH (H₂O)                       | 3.22 | Low      | 3.8 | Low      |
| N-total (%)                    | 0.91 | High     | 0.61| High     |
| Available-P (ppm)              | 14.12 | Low     | 6.02| Low      |
| Available-K (me/100 g)         | 0.41 | Medium   | 0.07| Low      |

Macro Nutrients Profile

Peatlands for A. crassicarpa ITE in Rasau Kuning District were set up by removing excess water through the drainage. This condition subsequently led to changes in soil condition that used to be reduced to be more oxidized. Changes in soil condition will lead to changes in soil organic matter decomposition rate, leading to nutrient mineralization. Nutrient mineralization in drained peatland occurs due to increased aeration in the surface peat layer, causing an increase microbial activity that plays a role in assisting nutrient mineralization [14]. There are 15 nutrients required by the plant which are classified into two main parts, namely macro and micro nutrients according to the amount of nutrients needed by the plant. Macro nutrient element is a relatively large nutrient element, and if one of them is eliminated it will endanger life and may even cause death. The elements are: C, H, and O derived from water and air, while elements like N, P, K, Ca, and Mg are derived from the soil. N, P, and K elements are called fertilizer elements, because they are needed in relatively huge quantities whereas their availability in the soil is usually insufficient for the plant needs.

N and P Profiles

Nitrogen is an extremely mobile element and is needed in large quantities, but the amount of available-N that can be directly utilized by plants in the soil is very small, therefore additional amount in the form of fertilizer shall be given to meet the needs. N nutrients are needed to improve plant’s vegetative growth and protein formation. The main source of N in the soil is organic matter. In general, it could be considered to be high or low depends on the level of decomposition of the organic material indicated by the C/N value. The high N value lies at a low C/N value, meaning that further decomposition process has taken place, as well as the opposite condition. The drainage process in peatland will cause faster decomposition process than in natural peatland, therefore generally the N
content will increase after drainage. There is a significant increase in N concentrations in the upper layer after drainage process on the oligo-ombrotrophic peatlands in Southern Finland [15].

The study pointed out an increasing tendency of N content on each peat depth point of the natural peatlands converted to ITE lands. The results of the significant difference test indicated that the average difference of N content is significant up to 250 cm peat depth. The result presented in Table 6.

A significant increase of N content up to a depth of 250 cm indicated that there has been an increase in decomposition process to such depths due to drainage on peatlands at the study sites as well as the effect of fertilizer application. The average N content based on differences in peat thickness in natural peatland ranges from 0.52-0.71 ppm, whereas in the ITE site it ranges from 0.71-1.23 ppm. Based on the criteria for peat soil fertility [13], these values are considered as high. However, it is generally existed in an unavailable form which can be directly utilized by plants due to high C/N ratio in the peat soil.

Table 6. Results of the average difference of N content in NF and IF locations based on the significant difference test.

| Peat Depth (cm) | N<sub>total</sub> Content (%) | Significance level of N concentration in NF and IF |
|----------------|-------------------------------|---------------------------------------------------|
| 0-50           | 0.71                          | 1.23 P=0.000, significantly different             |
| 50-100         | 0.58                          | 1.06 P=0.000, significantly different             |
| 100-150        | 0.72                          | 1.10 P=0.01, significantly different              |
| 150-200        | 0.67                          | 1.03 P=0.001, significantly different             |
| 200-250        | 0.63                          | 0.93 P=0.044, significantly different             |
| 250-300        | 0.66                          | 0.92 P=0.256, significantly indifferent            |
| 300-350        | 0.68                          | 0.80 P=0.495, significantly indifferent            |
| 350-400        | 0.52                          | 0.95 P=0.207, significantly indifferent            |
| >400           | 0.53                          | 0.71 P=0.128, significantly indifferent            |

The vertical distribution pattern of N content in natural peatland and ITE land (Figures 1 and 2) showed the highest concentration in the upper layer and then decrease linearly along with the increasing peat thickness, even though the pattern was less distinctive in natural peat location with R<sup>2</sup> = 0.32.

The second most essential nutrient after N is Phosphorus (P) [16]. P nutrient is a key component in life. Phosphorus in peat soils are largely derived from P-organic. A plant requires 0.3-0.5% of P of its dry weight for the optimum growth [17], whereas in peatlands it is only around 0.04% [6]. Phosphorus is an essential plant nutrient that is captured by plants in the form of anorganic ions: H<sub>2</sub>PO<sub>4</sub> <sup>-</sup> dan HPO<sub>4</sub> <sup>2-</sup> [18]. Phosphorus is responsible for roots growth, maintaining plant vigor, seed formation, and controlling plant maturity. It also serves as an essential component of ADP and ATP, and an essential part of nucleic acids (DNA and RNA) which function is controlling the synthesis of proteins and enzymes as genetic transfer component in cell division.
In most peat soils, phosphorus exists in the form of organic phosphorus compounds and only a small part is in the form of inorganic compounds. Organic phosphorus compounding could reach 75% in peat soil, whereas in mineral soils the average amount is about 3%. The inorganic P-form is generally more related to plant needs [19]. The average content of $P_{\text{available}}$ in the study sites presented in Table 7.

There is an increasing tendency of $P$ content at each peat depth point from natural peat to ITE land, although the results of the significant difference test indicated that the average difference of $P$ content significantly occurred only in the peat depth up to 100 cm. Increasing P content in ITE land may occur as a result of drainage so that the decomposition process of organic matters is faster than in natural peatland.

Table 7. Average content of $P_{\text{available}}$ (ppm) profile in research location.

| Peat Depth (cm) | $P_{\text{available}}$ Content (ppm) | Significance level of $P_{\text{available}}$ in NF and ITE |
|----------------|-------------------------------------|---------------------------------------------------------|
| 0-50           | 9.20, 36.32                         | $P=0.000$, significantly different                     |
| 50-100         | 5.70, 24.07                         | $P=0.000$, significantly different                     |
| 100-150        | 5.98, 14.58                         | $P=0.168$, significantly indifferent                   |
| 150-200        | 6.00, 15.57                         | $P=0.308$, significantly indifferent                   |
| 200-250        | 6.23, 10.27                         | $P=0.408$, significantly indifferent                   |
| 250-300        | 5.93, 7.25                          | $P=0.458$, significantly indifferent                   |
| 300-350        | 5.18, 7.13                          | $P=0.126$, significantly indifferent                   |
| 350-400        | 5.63, 7.77                          | $P=0.213$, significantly indifferent                   |
| >400           | 5.64, 6.38                          | $P=0.19$, significantly indifferent                    |

The average P content based on differences in peat thickness in natural peatland ranges from 5.18 to 9.20 ppm and considered to be low criteria. The vertical distribution pattern of P content in natural peatland showed the highest concentration at the upper layer, then appeared to decrease linearly with the increasing of peat thickness. The average P content in the ITE vertically ranges from 6.38-36.32 ppm which belong to low to moderate criteria. The vertical distribution pattern of P content in ITE land is similar to that in natural peatland, but with stronger correlation ($R^2 = 0.76$) (Figures 3 and 4).

Figure 3. Vertical distribution pattern of P content in natural peatland location.  
Figure 4. Vertical distribution pattern of P content in IF location.

K Profile
K element in the soil is derived from soil minerals and fertilization activities. It has a particular functions in the formation of starch, activating enzymes, as well as physiological and metabolic processes in plant cells. In the soil, K can be divided into: (1) unavailable for plants, contained in

\[
y = -0.2687x + 7.5089  
R^2 = 0.3909
\]

\[
y = -3.198x + 30.361  
R^2 = 0.7626
\]
primary mineral soils such as feldspar. Total K in the soil ranges from 90-98%; (2) available, consists of interchangeable K and K in solution (K$^+$). Its amount in the soil is 1-2%; (3) available but slow, K that can not be exchanged, bound by clay mineral; is not washed away by rain water and can be transformed into available forms. Several studies on the changes in K content due to drainage were carried out [21, 15]. In this study, the K content was greater in drained soils than in natural peatlands. The average K contents in natural peat compared to drained peat were significantly different at each depth points of the peat (Table 8).

The average K content based on differences in peat thickness in natural peatlands ranges from 0.05-0.10 c mol/kg, which is considered to be low according to the criteria for soil fertility as argued by [13]. Vertical distribution pattern of K content in natural peatland indicating the highest concentration in the upper layer then appeared to decrease but does not have a clear pattern as peat thickness increased. The average K content based on the peat depth in the ITE site is 0.43 c mol/kg which is classified as medium. In contrast to the K content in natural peat sites, the highest K content in the ITE site is found in the lower layers, whereas the lowest K content is in depths of 50-100 cm. The depth is an effective root depth area for A. crassicarpa plant, enabling K to reduce considerably as it is absorbed by plants. The K content in the deeper peat layers can not offset the absorption of K by the plant.

Table 8. Average content of K profile in research location.

| Peat Depth (cm) | $K_{available}$ Content (c mol kg$^{-1}$) | Significance level of $K_{available}$ in NF and ITE |
|----------------|----------------------------------------|-----------------------------------------------|
| NF            | ITE                                    |                                              |
| 0-50          | 0,10                                   | P=0,000, significantly different              |
| 50-100        | 0,07                                   | P=0,005, significantly different              |
| 100-150       | 0,06                                   | P=0,000, significantly different              |
| 150-200       | 0,05                                   | P=0,000, significantly different              |
| 200-250       | 0,07                                   | P=0,000, significantly different              |
| 250-300       | 0,08                                   | P=0,001, significantly different              |
| 300-350       | 0,08                                   | P=0,000, significantly different              |
| 350-400       | 0,09                                   | P=0,050, significantly different              |
| >400          | 0,08                                   | P=0,001, significantly different              |

Ca Profile
Calcium (Ca) is one of the essential macro nutrients responsible in cell wall adhesion and is important in plant cell division. Ca may increase the pH and possess a beneficial effect in the development of soil structure. Ca element has a specific role in activating a number of enzymes and it is responsible in N metabolism by participating in nitrate reduction [22].

In this study, Ca content were greater in drained soils than in natural peatlands (Table 9). Its average differences were significant to a depth of 250 cm. It is occurred due to the decomposition process after drainage that produces dissolved organic acid which tends to decrease soil pH. Furthermore, the soil responds by releasing interchangeable base cations, resulting in increased Ca concentrations after drainage [23,24,25].

Table 9. Average value of Ca content in the research locations.

| Peat Depth (cm) | Ca Content (c mol kg$^{-1}$) | Significance level of Ca concentration in NF and ITE |
|----------------|-----------------------------|-----------------------------------------------------|
| NF            | IF                          |                                                     |
| 0-50          | 0,63                        | 3,10                                                |
| 50-100        | 0,74                        | 2,60                                                |
| 100-150       | 0,65                        | 2,34                                                |
| 150-200       | 0,69                        | 2,30                                                |
| 200-250       | 0,76                        | 1,88                                                |
| 250-300       | 0,86                        | 1,58                                                |
| 300-350       | 1,36                        | 1,64                                                |

P=0,000, significantly different
The vertical distribution pattern of Ca content found in NF is the increasing Ca concentration as peat thickness increased. It is may due Ca is an immobile nutrient. Its addition is unexisted through fertilization in natural peat, while the nutrients are continuously consumed by plants. Therefore, Ca content in the upper layer appeared to be the smallest. In contrast to the distribution pattern in natural peatlands, the highest Ca content in ITE land present in the topmost layer, then decreases according to the increasing peat thickness. This condition is required to improve A. crassicarpa vitality. Phosphate were added to increase pH before planting, therefore the highest Ca content existed in the top layer. Ca content begins to decrease in the root zone, usually above the groundwater depth [26].

**Mg Profile**
Magnesium (Mg) is a macro essential nutrient which role is in forming chlorophyll and can not be replaced by other elements. This element is absorbed by plants in the form of Mg$^{2+}$ cations, most of which are derived from soil solution through less mass streams compared to Ca or K. Results of the analysis on Mg content in the study sites are presented in Table 10.

| Peat Depth (cm) | Mg Content (cmol kg$^{-1}$) | Significance level of Mg concentration in NF and ITE |
|----------------|---------------------------|-----------------------------------------------------|
| 0-50           | 0.72, 1.97                | P=0.000, significantly different                     |
| 50-100         | 0.82, 1.11                | P=0.05, significantly indifferent                    |
| 100-150        | 1.50, 0.87                | P=0.14, significantly indifferent                    |
| 150-200        | 1.41, 1.30                | P=0.81, significantly indifferent                    |
| 200-250        | 2.00, 1.21                | P=0.02, significantly indifferent                    |
| 250-300        | 1.70, 1.51                | P=0.63, significantly indifferent                    |
| 300-350        | 2.44, 1.48                | P=0.10, significantly indifferent                    |
| 350-400        | 2.00, 3.29                | P=0.24, significantly indifferent                    |
| >400           | 2.78, 3.16                | P=0.002, significantly different                     |

At the two uppermost and lowermost layers, the average Mg content in ITE locations is greater than in the natural peat. The difference in significance level of Mg concentration in natural peat and ITE is only significant in the depth of 0-50 cm and above 400 cm. The value of Mg content in natural peat ranges from 0.59-3.62 cmol/kg, with an average value of 2.01 cmol/kg which belongs to high criteria. Whereas the Mg content in the ITE ranges from 0.28 to 5.05 cmol/kg, with an average value of 1.42 cmol/kg that is classified as medium criteria. Gandini [21] findings pointed out that the amount of Mg content appears to be affected by the distance between the land and the nearby river. The land close to the river with shallow groundwater and flooded surfaces during high tide, indicated a higher Mg content especially in the lower layers. The average Mg content in natural peatlands is greater than in the ITE land, since natural peatlands are often inundated periodically.

### 4. Conclusion
A vertical peat distribution study showed that there is a higher tendency of macro nutrient values of N, P, K, and Ca in ITE larger than in the natural peatlands, except for the average Mg content. Increased N and P contents occurred at each depth point on ITE land. The difference in average N content between natural peat and ITE is rather significant up to 250 cm peat depth, whereas the P is only up to 100 cm depth. In contrast to the N and P contents, the highest K content in ITE sites is found in the lower layers, whereas the lowest K content is found at 50–100 cm depth, indicating that lots of K content were lost as it is absorbed by plants and lost due to drainage. Similar to N content, the average Ca content in natural peat compared to drained peat is significantly different up to a depth of 250 cm.
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