Understanding nutrient cycles as a key to sustainable forest plantation on tropical peatland in Indonesia

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Abstract. Indonesia has around 14 million ha of peatlands which constitutes 7.4% of Indonesia’s land area and very potential to be developed to support national development, especially related to economic strengthening and in enhancing employment opportunities. An expand areas of peatlands in Indonesia are already being utilized for forest plantation of Acacia crassicarpa. To gain clues in understanding how the chemically poor ecosystems can support the plantation, nutrient cycles. The research was carried out in Acacia crassicarpa plantation areas in South Sumatra, Jambi, and Riau, respectively representing shallow, medium, and deep peat. Data collection includes chemical characteristics of the peat, decomposition rate of the litter, fluctuations of the water table, and growth and production of the Acacia crassicarpa. The results show that: a) Acacia crassicarpa growth and production on peatlands much more depend on the nutrient cycles than on the chemical characteristics of the original soil; b) Leaf-fall and the speed of decomposition respectively from the highest to the lowest, are Riau (deep peat), South Sumatra (shallow peat), and Jambi (medium peat); and c) The more leaf-fall produced and the faster the decomposition, the faster is the nutrient cycles and hence the highest is the production of plant biomass.

1. Introduction

The nation’s need to cultivate land to meet social needs and produce economic goods clearly continues and increases. On the other hand all primary and easy land has been used for decades and therefore vacant lands has been already scarce. Among the remain vacant lands since the few past decades include the peatlands, those unfortunately are fragile in nature. Ever since then there is no doubt remain that peatlands in Indonesia became important parts of Indonesia’s land resources for use in economic development regardless their fragility. The reclamation of shallow peatlands in the past for development of rice field under governmental projects in 1970s is one of the records of how these flat, swampy, and peat covered lowlands have been extensively utilized for social and economic development [1]. Following these governmental projects then the use of peatlands by the private sector for oil palm, rubber and industrial forest plantations has also became quite expansive.

The experience gained over decades in utilizing Indonesian peatlands provides great lessons, including success stories and failures. From the rice field development projects in these swamp areas, the lessons were mostly the project failures to finally get sustainable productive rice fields. The causes of failures are clearly complicated but the application of inappropriate land management is one of the main causes. The most prominent aspect of land management that led to the failure of the Mega Rice project in Central Kalimantan during the late 1990s, for example, was an improper canal system that caused the peatlands to drastically thinning and even lose its peat layer and hence opened up a layer containing sulfide to the surface and the sulfide solids were rapidly oxidized to enormously acidify the soil and the water system. The oxidation of pyritic layer due to the loss of peat layer upon because of an inappropriate water management was described by [2].

In contrast to the rice field development projects, the use of Indonesian peatland for industrial forest plantation gave mostly success stories in that for some plantation areas after some rotation (5 years each) the utilization is still steadily productive and environmental deterioration is constantly eluded. Only one species of timber sources is so far reported successfully cultivated on peatlands, that is Acacia crassicarpa. Proper water management to control water table to keep fluctuating within the
optimum depths is well considered as the most determining factor for the productivity of this species on peatlands. The fertilization of the growing trees is even applied at minimum rate at only the initial growth phase of this species that is a leguminous plant.

The secure productivity of *Acacia crassicarpa* plantation on peatlands is not necessarily gained at anywhere but it went variously, which is likely depend on the specific nature of the peatland of each area. The rate of fertilization was of course always set based on nutrient availability of the respective peat (peat soil) and the water management also was engineered based on the hydrological condition of the landscape. Still that the productivity variation occurred even so significant. A field observation of the growing *Acacia crassicarpa* on peatlands of three different sites has resulted in visual records reflecting the nutrient sources, the nutrient availability and the nutrient uptake mode by the plants. These records suggest that nutrient cycles play as the key to sustainable *Acacia crassicarpa* plantation on peatlands. Many report underlined the importance of nutrient cycle in forest ecosystem, such as the research conducted by [3] mainly discussed about nutrient cycle in a Tropical *Acacia mangium* Willd. Plantation in Northern Vietnam. This article would provide an elaboration of how nutrient cycles work in the *Acacia crassicarpa* plantation on peatland by correlating the field observation records with some respective productivity figures of the sites as well as the peatland characteristics and the management.

2. Materials and Methods

Most of the data discussed in this study are parts of data of a research on carbon dynamics in peatland planted forests in Sumatra that was reported by [4]. This study focus on the nutrient cycle aspect in relation to the productivity of *Acacia crassicarpa* plantation on the research areas that was not indepthly depicted in the report book. Therefore, presentation of data in this study are not totaly the same as they are presented in the book and the focus of discussion is new.

2.1 Study sites

The studied peatland area comprises of three sites having different peat depth, namely shallow (less then 1.5 m) peat, moderate (1.5 to 3 m) peat and deep (more than 3 m) peat. All the three sites are being cultivated for *Acacia plantation* at first and second rotation.

The shallow peat site is located in South Sumatra Province, which has been around 30 years since it was opened by the community and during the collection of data used in this study, the site was in the first rotation of the *Acacia crassicarpa* plantation after being abandoned for a long time. The site of moderate peat is located in Jambi Province that has elapsed for 9 years since the conversion and the site of deep peat is located in Riau Province that has elapsed for 11 years since the conversion; both were at the second rotation of plantation at the collection period of data used in this study.

2.2 Data compilation and presentation

Already mentioned above that most of data in this study were obtained in a research on carbon dynamics in tropical peatland [5]. Here are selected data for use in this study. The selected data include (1) chemical and physical characteristic of peat, (2) litter decomposition rate, (3) chemical content of *Acacia crassicarpa* leaf, (4) *Acacia crassicarpa* biomass production, and (4) water table fluctuation. The data were interpreted descriptively by considering the logic of chemical, physical, and biological processes.
3. Results and Discussion
Characteristics of peat of each study site are presented in Table 1. There are no significant differences between those of shallow, moderate-deep and deep peat especially with respect to the nutrient content. The low nutrient content of the peat of the study area is of typical nature of tropical peat including those over the country of Indonesia as extensively reported elsewhere. For the case of these three study sites, since the bulk density of these three are very low (0.1 - 0.2 gr/cc) then the nutrient content per volume is counted to be even more low.

Despite the low fertility of Indonesian peat as represented by the data of these sites, the productivity of Indonesian peatland wherever being used for industrial forest plantation, especially of *Acacia crassicarpa* is reported quiet satisfactory. Up to present there are not less than 1.5 million hectares peatland are being planted by *Acacia crassicarpa* to supply the timber to some pulp and paper factories. [5] reported that the production of pulp and paper in Indonesia until 2013 was 4.55 million ton (number 9th in the world) and 7.98 million ton (number 6th of the world), respectively.

The tree stand population, weight per stand and total biomass per ha of *Acacia crassicarpa* of each study site are shown in Table 2. The data exhibit a significant difference in the weight per stand of *Acacia crassicarpa* obtained for each study site that differed from each other in the peat depth. The highest weight per stand was found for the shallow peat (441 kg/tree) followed by the deep peat (345 kg/tree) and the moderate-deep peat gave the lowest and a far lower figure (only 165 kg/tree) than the two others. This order seems irregular with respect to theoretical base that the thickest the peat the poorest in nutrient content in that by this theory then the moderate peat should has better plant growth than the deep peat.
Table 2. The tree stand population, weight per stand and total biomass per ha of *Acacia crassicarpa* of each study site

| Stand Age (years) | Population (streams) | Weight/tree (kg) | Total Biomass (Tons) |
|------------------|----------------------|------------------|----------------------|
|                  | Shallow | Medium | Deep Peat | Shallow | Medium | Deep Peat | Shallow | Medium | Deep Peat |
| 1                | 1800    | 1767   | 1933      | 54.70   | 5.80    | 16.00     | 98.50   | 10.30  | 32.30 |
| 2                | 1600    | 1800   | 2267      | 102.80  | 40.30   | 42.70     | 164.40  | 72.50  | 96.80 |
| 3                | 1533    | 170    | 1967      | 162.40  | 106.40  | 83.60     | 249.00  | 180.90 | 164.40 |
| 4                | 1033    | 1233   | 1700      | 251.70  | 155.00  | 157.40    | 260.00  | 191.10 | 267.60 |
| 5                | 821     | 1010   | 1411      | 441.70  | 165.30  | 345.00    | 362.00  | 166.90 | 486.80 |

Table 2 also shows remarkable differences in the harvested population (at 5 years stand age) and the respective total biomass production. The seedlings planted was 1666 per ha for all the sites, but due to some trees would grow directly from abandoned seeds on the ground and some trees died anytime during the 5 years growth period then the final population was found quite different. The final population from the highest to the lowest was 1441 trees/ha, 1010 tree/ha and 821 trees/ha from the deep peat, the medium peat and the shallow peat respectively. Again to note that this order is contradictory with the theoretical fertility order of peat with regard to the thickness. The total biomass gained at the harvesting age has the same order with that of the weight of stand in that the total biomass of the *Acacia crassicarpa* from the deep peat was the highest (486 ton/ha) followed by that of the shallow peat (362 ton/ha) and the moderate peat gave the lowest and a far lower figure (only 166.9 ton/ha) than the two others.

Theoretically considered irregular order of the figures of the growth parameters depicted above has raised a question on the causing factors in resulting the high and low productivity of the *Acacia crassicarpa* plantation on these depth-differing peat sites. The rate of fertilization applied for all the sites was the same, thus there must be other differentiating factor(s) involved during the growth period.

A field observation focused on the rooting system of the *Acacia crassicarpa* trees on the sites provided a picture that most medium and fine roots of the plants are concentrated on around the surface down to around 20 cm in the peat ground. In addition to the on surface concentrated fine and medium roots, it was also found that abundant of the fine roots are attached on the surface of the decaying leave litters (see Figure 1). It is likely that the roots directly absorb the nutrients just released from decomposed tissues of the fallen leaves.

![Figure 1](image_url)

Figure 1. Fine roots of *Acacia crassicarpa* around decaying leaf litters.
To back up this prompt interpretation on the possible mode of the nutrient uptake by the *Acacia crassicarpa*, the result of the fresh and decomposed leaves analyses for the nutrient content is presented in Table 3. Comparison of the nutrient content in the fresh leaves to those of partly and fully decomposed leaves shows significant decrease of the content of almost all the nutrients in the decomposing leaves. This fact has drawn an understanding that there is a continuous release of nutrients along with the decomposition process of the fallen leaves outer tissues. The attachment of the fine roots just on the surface of the decomposing leaves is therefore certainly related to this phenomenon. By this mechanism the roots effectively uptake the just released nutrients right before they incorporated in the peat particles. Once the released nutrients incorporated in the peat layer they will not be easily uptaken by the roots anymore. Chelation (especially of micronutrients), dilution effect and the further leaching are among the constraints for the *Acacia crassicarpa* roots to gain the availability of the nutrients.

**Table 3.** Nutrient content of fresh and decomposed leaves

| Site                  | Moderately-Deep Peat | Deep Peat |
|-----------------------|----------------------|-----------|
| Sample                | Ac Fresh Litter      | Ac Partly Weathered Litter | Ac Weathered Litter | Ac Fresh Litter | Ac Partly Weathered Litter |
| %                     |                      |          |            |            |
| C                     | 49.77                | 51.35    | 49.82      | 46.71      | 45.18    |
| N                     | 3.38                 | 1.32     | 1.91       | 2.96       | 1.58     |
| S                     | 0.34                 | 0.02     | 0.03       | 0.28       | 0.03     |
| C/N                   | 14.7                 | 39       | 26.1       | 15.8       | 28.3     |
| ppm                   |                      |          |            |            |
| P                     | 0.14                 | 0.07     | 0.08       | 0.17       | 0.15     |
| %                     |                      |          |            |            |
| K                     | 1.17                 | 0.11     | 0.05       | 1.76       | 0.09     |
| Na                    | 0.32                 | 0.05     | 0.02       | 0.58       | 0.2      |
| Ca                    | 0.42                 | 1.46     | 0.32       | 0.91       | 2.32     |
| Mg                    | 0.24                 | 0.2      | 0.06       | 0.32       | 0.34     |
| ppm                   |                      |          |            |            |
| Fe                    | 297.7                | 369.1    | 1727.6     | 195.1      | 214.1    |
| Mn                    | 137.2                | 209.4    | 484.2      | 74.2       | 327.6    |
| Cu                    | 1.6                  | 4.2      | 7.6        | 17.4       | 6.5      |
| Zn                    | 0.1                  | 0.1      | 0.1        | 29.9       | 1.1      |

Based on the insights drawn above, the amount of the litter leaves and the rate of the decomposition would therefore have significant roles on the nutrient supply to the plant growth. These two factors might strengthen or weaken each other. At the normal condition, the most vigorous and healthiest the trees the most the leaves amount will fall and the highest the population the highest the total amount of fallen leaves. The highest amount of fallen leaves (6.38 ton/ha/yr) is belong to the plantation on the deep peat site (Table 4) that is in accordance to the respective high weight per stand and the highest population. The amount of fallen leaves at the shallow peat site (5.08 ton/ha/yr) is lesser than that of the medium peat (5.83 ton/ha/yr) but it is not far lesser as the population is, as there is a compensation from the weight per stand of the trees on the shallow peat that instead is the highest.

**Table 4.** The amount of fallen leaves of *Acacia crassicarpa* in each study site in 2011

| Month     | Shallow | Medium | Deep Peat |
|-----------|---------|--------|-----------|
| January   | 100     | 100    | 100       |
| February  | 74.42   | 64.84  | 67.31     |
| March     | 58.65   | 64.84  | 68.28     |
| April     | 57.77   | 65.87  | 64.69     |
| Month   | Shallow | Medium | Deep Peat |
|---------|---------|--------|-----------|
| May     | 56.16   | 68.84  | 48.76     |
| June    | 47.73   | 57.30  | 41.17     |
| July    | 45.18   | 55.64  | 39.48     |
| August  | 45.18   | 54.94  | 34.72     |
| September | 45.18 | 59.68  | 38.75     |
| October | 43.58   | 53.70  | 31.25     |
| November | 38.68 | 57.02  | 25.91     |
| December | 30.12  | 48.22  | 18.89     |
| Total per years (ton/ha) | 5.08 | 5.83 | 6.38 |

The decomposition rate of the litter leaves of the deep peat is also the highest (Figure 2) followed by those of the shallow peat and the moderate peat. Thus it is important to be underlined here that the role of each the amount of the litter leaves and the rate of the decomposition happen on the deep peat site has strengthen each other in continuously supplying back the growing trees with the nutrients.

![Figure 2](image.png)

**Figure 2.** The decomposition rate of the litter leaves of *Acacia crassicarpa* in each study site

The explanation depicted above is indeed satisfactory to answer the question of how possible a survival and sustainable plantation of *Acacia crassicarpa* could be achieved on this chemically poor peat. But there is still a need to obtain a logic of how possible does the deep peat (at least for the case of this study sites) become the best for *Acacia crassicarpa*? The answer is hanging on the understanding of the physiographical and hydrological nature of the respective peatlands. The deep peat plantation site is located on the edge of a peat dome. The peat dome is definitely a huge fresh water reservoir that anytime can supply the water to the plantation area. Engineering of water management of peatland area located at the edges of the peat dome seems worked well all the seasons.
that no dryness during dry season and no flood during high rainfall season. Hence in this deep peat site the peat always has water table at the optimum level for the plant growth.

In the contrary, the optimum hydrological condition at the other two sites (shallow and moderate peat) was not necessarily achieved (Figure 3). At the shallow peat site there is a condition when the water table could go down to 100-150 cm regardless the effort that has been made in engineering the water management. This situation happen regularly at each dry season due to the lack in natural water reservoir connected to the site since the site is part of a tidal flat but the tide cannot overflow the land anymore. On the other hand at the moderate peat site, even after the water management is designed there were still flood and quiet lengthily water inundation happen each year. This condition reflects the nature of its geomorphology that is part of a backswamp. An improvement of the canaling system may be need to overcome the problem for this site.

4. Conclusion
The growth and production of *Acacia crassicarpa* depend more on the nutrient cycle than on the chemical nature of the original soil. The higher the leaf fall and the faster the litter decomposition will result in a faster nutrient cycle and hence higher plant biomass production. It was found that for the three sites studied here the order of leaf fall and speed of the litter decomposition from the lowest to the highest with respect to peat depth is deep peat > shallow peat > moderate peat. This order has a strong correlation with the level of difficulty in water management, namely that water management was successfully engineered to achieve an optimal water level in whole year in the deep peat area located next to a peat dome and was less successful in the area of shallow peat located at a tidal flat and was much less successful in the area of moderate peat located at a backswamp.
References

[1] Sumawinata B, Darmawan 2009 Current issues on tropical peatland in Indonesia. *Proceedings of Bogor Symposium and Workshop on Tropical Peatland Management 2009*

[2] Sumawinata B 1992 Adaptive agricultural practices and land use cycles on pyritic sediments in South Kalimantan. *Southeast Asean Studies* 30 93

[3] Bich N V, Eyles A, Mendham D, Dong T L, Ratkowsky D, Evans K J, Hai V D, Thanh H V, Thinh N V and Mohammed C 2018 Contribution of harvest residues to nutrient cycling in a tropical *Acacia mangium* Willd. Plantation. *Forests* 9 577

[4] Sumawinata B, Djajakirana G, Suwardi, Darmawan 2014 *Carbon Dynamics in Tropical Peatland Planted Forests* Bogor: IPB Press

[5] Ministry of Industry 2016 The Republic of Indonesia is the number six of paper producer of the world. *Pikiran Rakyat.*