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# Impact of Thinning of *Acacia Mangium* Plantation on Soil Chemical Properties

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## ABSTRACT

This study was conducted to determine soil organic carbon, nitrogen, available phosphorus and pH at 3 soil depths under different ages and cycle of *Acacia mangium* after thinning of planted forest as well as to determine their variability in a tropical forest. Composite soil samples were collected at depths of 0 - 5, 5 - 10 and 10 - 30 cm in each plot and were analyzed for organic C, total N, available P and pH. Composite surface litters were analyzed for total C, N, P, Ca, Mg and K. Soil C and N were significantly higher at 0 - 10 cm depth in the 2nd cycle of *A. mangium* which were 0 - 3 months older than the natural forest. Available phosphorus decreased in the 1st rotation of *Acacia mangium* of more than 20-year-old stands and in plots which underwent thinning. Soil C, N, P decreased with increasing soil depth. Calcium in leaf litter of more than 20-year-old stands was significantly lower than in the other study plots. N, P and K concentrations were higher in leaf litter of thinned plots and in more than 20-year-old stands.

**Keywords: Soil properties, tropical, planted forest, rotation, selective harvesting**

## INTRODUCTION

The continuous demand for timber supply in the global market has prompted tropical countries including Malaysia to provide timber for world market consumption. Various measures were undertaken to establish plantation forests under the Compensatory Forest Plantation Project (CFPP) using species such as *Acacia mangium, Gmelina arborea* and *Paraserianthes falcataria* for producing general utility timber (Varmola 2002). *Acacia mangium* is one of the popular fast growing species found in South-East Asian forest plantations. Belonging to the *Leguminosae* family, this species was first introduced to Malaysia in the early sixties (Ahmad Zuhaidi 2002). The timber from *Acacia* may be sold for about USD 73 $m^{-3}$ and is currently utilised as raw materials for the sawn timber, veneer, and pulp and paper industries (Malaysian Timber Industry Board 2007). This

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species is known to have a symbiotic relationship with soil microbes (Lee *et al.* 2006) which enhance soil C and N uptake (Rillig and Allen 1999).

The current surge in climate change research, and the depleting supply of renewable energy such as wood, has pushed the sustainable forest management concept into the limelight of the present decade. This has persuaded stakeholders to meet their clients' demand of managing plantations on a sustainable basis. A well developed forest management plan which includes selective thinning (the removal of trees selectively to improve the growth rate or health of the remaining trees) and optimum harvesting techniques (Rice *et al.* 2001) is essential for this purpose. Nevertheless, human-induced changes such as felling, thinning, shifting cultivation and replanting will have impacts on soil nutrients pools, thus altering the soil nutrient content (Batjes and Sombroek 1997).

Carbon, N and P are essential nutrients important for the establishment of favorable timber plantation stands. Unfortunately, most of the tropical soils have low levels of these nutrient reserves, low nutrient retention ability and are prone to drought (Tiarks *et al.* 1998). Organic C and N are important constituents of wood biomass of *A. mangium* (Nykvist and Sim 2009). Phosphorus availability is critical for the suitable growth and height of *A.mangium* (Nik Muhammad and Paudyal 1999) but this element is hardly available in acidic tropical soils with low pH conditions (Tiessen 1998). Thus, the question of how much of these nutrients are available in soil after thinning activities have been carried out arises. Better information on the soil chemical nutrient status will allow forest plantation owners to manage their production forest in the most effective and efficient way. This study was conducted to quantify the soil organic C, N, and P and to determine soil pH under different ages and rotation of *Acacia mangium* after thinning as well as to determine their distribution according to soil depths. Information on the soil chemical status after thinning will assist forest managers to strategize future management practices.

## MATERIALS AND METHODS

*Site Description*

The research plot was established in Kemasul Forest Reserve, Mentakab, Pahang, Peninsular Malaysia (102° 14' East and 3° 25' North) located 80 m above sea level. The area was planted with *A. mangium* with 3.7 x 3 m spacing by the Forestry Department of Pahang (Kemasul), Malaysia under the Compensatory Forest Plantation Project (CFPP) in 1982. Prior to planting, a semi-detailed soil survey was carried out and the soil chemical properties are presented in Table 1. During planting, 50 g of Christmas Island Rock Phosphate (CIRP) was incorporated into the planting hole. The fertilizer NPK Blue 12:12:17:2 was applied every 6 months for the first 2 years, thereafter at 100 g of fertilizer/tree to promote tree growth. The plantation consisted of 4 major blocks with various sizes with a total area of approximately 4100 hectares. However, only 3 out of 4 blocks which underwent thinning were selected for this experiment which was initiated in August 2007.

TABLE 1
Initial soil chemical properties of Durian and Bungor series soil at site

| | Durian soil series | | Bungor soil series | |
|---|---|---|---|---|
| Depth (cm) | 0-10 | 10-30 | 0-10 | 10-30 |
| Soil Properties | | | | |
| Organic C (%) | 1.38 | 0.58 | 1.5 | 0.43 |
| Total N (%) | 0.12 | 0.06 | 0.12 | trace |
| Available P (mg $kg^{-1}$) | 2.90 | 2.00 | 2.60 | 1.50 |
| K ($cmol_c$ $kg^{-1}$) | 0.16 | 0.08 | 0.10 | 0.06 |
| Ca ($cmol_c$ $kg^{-1}$) | 0.39 | 0.35 | 0.30 | 0.15 |
| Mg ($cmol_c$ $kg^{-1}$) | 0.23 | 0.09 | 0.27 | 0.08 |
| pH (water) | 4.72 | 4.61 | 4.62 | 4.91 |

Source: Amir Husni (1983)

The area had a flat to slightly undulating terrain. Soil was formed from sedimentary and metamorphic rocks with a sandy clay loam texture, mainly classified as Bungor (*Typic Paleudult*) and Durian (*Plinthaquic Paleudult*) soil series. Mean daily air temperatures ranged from 27-32 °C with an annual rainfall of between 1800 and 2030 mm. The wettest months were August, November and December.

*Plot Designation and Sampling*

The plots were as follows:

i) P1: Natural forest (control),
ii) P2: A.mangium 1st rotation of more than 20-year-old stands,
iii) P3: *A.mangium* 2nd rotation of 4-year-old stands,
iv) P4: *A.mangium* 2nd rotation of 3-6 month-old seedlings
v) P5: *A.mangium* 2nd rotation of 0-3 month-old seedlings

Common trees which were found in the natural forest (P1) were *Endospermum malaccences, Shorea leprosula, Sapium baccatum and Trema orientalis* (L.). The second plot (P1) had 1st rotation of *A. mangium* stands of more than 20 years. Usually, each rotation constitutes a full life cycle of a tree which can be harvested for trading purposes. The other sites had undergone standard silvicultural practices of thinning at harvesting and the *A. mangium* were allowed to regenerate naturally (P3 - P5). The plots were only divided into 3 equivalent size replicates, measuring 20 m x 20 m each as some of the other areas within the plots were not accessible and were heterogeneous due to their topography. Three subsamples of the soil were taken in each replicate plot after thinning activities to prepare a composite sample at soil depths of 0 - 5, 5 - 10 and 10 - 30 cm from the soil surface. A total of 9 composite soil samples were collected for each plot representing each soil depth. Surface litter samples were also collected using the same procedure. A 30 cm x 30 cm wooden frame was placed on the soil surface and litter material was collected manually and brought to the laboratory.

*Analysis*

Prior to analysis, soil samples were air dried until constant weight before crushing through a roller mill and passed through a 2-mm sieve. Soil samples were subjected to organic carbon analysis according to Walkey and Black method and soil nitrogen was determined using Kjedahl digestion (Malaysian Standard 678 1980). Available P was determined by Bray and Kurtz Method No.2 (Bray and Kurtz 1945). The pH of the soil was determined in 1:2.5; soil: water slurry. Litter samples were oven-dried at 60 °C until constant weight according to standard FRIM soil chemistry laboratory practice before grinding using a mechanical grinder and passed through 1-mm sieve. Subsamples were put into a furnace at 500° C for 5 hours for dry ashing and followed by dissolution in nitric acid (Malaysian Standard 677 1980). The samples were analyzed for N, P, Ca, Mg, and K, using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP - OES). The soil and litter results were analyzed using one-way ANOVA. Tukey test was used for means comparison using Statistical Analysis System version 8.12 (SAS 2001).

## RESULTS AND DISCUSSION

*Soil Chemical Properties*

The organic C content of P5 was the highest among all treatments at 0-5 cm soil depth. It was 4- fold significantly higher compared to P1 (Table 2). Soil organic C pool in P2, P3 and P4 was the same. Organic C content at different forest types and rotations hardly showed any changes at 5 - 10 and 10 - 30 cm depth.

The total soil N in P4 and P5 were significantly higher, by 63 % and 75 %, respectively, compared with P1 at 0 - 5 cm depth. At 5 - 10 cm depth, P2, P3 and P4 were similar to control (P1) unlike P5, which maintained higher soil N compared to P1. No significant differences were found at 10 - 30 cm soil depth.

Soil available P in 0 - 5 and 5 - 10 cm soil depths were not significant for all plots. However, the levels were significantly higher in P1 compared to P2 and P5 at 10 - 30 cm depths. Soil available P was very low in all plots of *A.mangium*, which were less than 2.5 mg $kg^{-1}$. Generally, pH ranged between 3.8 and 4.5 for all plots and did not show any significant differences. The content of organic carbon, nitrogen, available phosphorus and pH decreased with increasing soil depth for most of the plots.

The high organic C in the 2$^{nd}$ rotation of plantation of 0-3 months old seedlings (P5) shown in Table 1 compared with natural forest and the initial soil chemical properties is due to many factors. The formation of new roots of the nitrogen fixing legume in the 2$^{nd}$ rotation may have boosted the soil C and N content. Roots play an important role in preserving carbon stocks below ground levels. Thus, a substantial amount of C (3.16%) was found in P5. Workers have also pointed out that large residues of coarse roots (Bolstad and Vose 2005) and fresh organic debris (Bruijnzeel 1998), which remained *in situ* after thinning, provided ample feed for soil and plant microbial activities, leading to soil carbon stocks (

TABLE 2
Soil organic C, total N, Available P, and pH of natural forest and different age classes of *Acacia mangium* plantation at research site

| Concentration / Soil depth (cm) / Site | Organic C (%) | | | Total N (%) | | | Av. P (mg kg$^{1}$) | | | pH (water) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-5 | 5-10 | 10-30 | 0-5 | 5-10 | 10-30 | 0-5 | 5-10 | 10-30 | 0-5 | 5-10 | 10-30 |
| Natural Forest (P1) | 0.74 b | 0.79 | 0.65 | 0.08 b | 0.06 b | 0.06 | 3.21 | 1.46 | 1.25 a | 4.07 | 4.21 | 4.54 |
| 1st rotation (P2) > 20 years | 2.41 ab | 1.14 | 0.92 | 0.13 ab | 0.08 ab | 0.08 | 2.17 | 0.98 | 0.37 b | 4.36 | 3.98 | 4.18 |
| 2nd rotation (P3) 4 years | 1.83 ab | 1.41 | 1.08 | 0.10 ab | 0.09 ab | 0.07 | 2.01 | 1.32 | 1.03 ab | 4.49 | 4.32 | 4.23 |
| 2nd rotation (P4) 3-6 months | 1.88 ab | 0.74 | 0.65 | 0.13 a | 0.08 ab | 0.06 | 2.46 | 1.31 | 0.81 ab | 3.82 | 4.09 | 4.19 |
| 2nd rotation (P5) 0-3 months | 3.16 a | 1.72 | 0.92 | 0.14 a | 0.10 a | 0.08 | 1.77 | 1.07 | 0.38 b | 3.98 | 3.95 | 4.16 |
| SE | 0.28 | 0.13 | 0.06 | 0.07 | 0.00 | 0.00 | 0.25 | 0.13 | 0.10 | 0.14 | 0.05 | 0.05 |
| F test | * | ns | ns | ** | ** | ns | ns | ns | ** | ns | ns | ns |

SE: standard error *-significant at 0.05 level **- significant at 0.01 level ns – not significant
Individual values in columns with the same letters are not significantly different at $p \geq 0.05$ according to Tukey test

(Binkley *et al.* 2004). Other factors which may have contributed to the different levels of C in natural forest and treated plots would be pH, microbial population and organo-mineral interactions (Motavalli *et al*. 1995).

The increased soil N in P4 and P5 compared to P1 may be due to the nature of the nitrogen fixing species such as *Acacia* (Power *et al*. 2003) which fertilized the soil as well as residues from previous fertilizer applications. Elevated organic C and N content in 2nd rotation is also due to the leaching effect after thinning activities. Carbon and N which constitutes an integral part of organic matter naturally undergoes leaching due to microbial activity, temperature and soil respiration (Andersson *et al*. 2002). Leaching rates were increased due to gaps created in the forest floor mainly for two reasons, that is, the increased percolation of water and the increased solute levels in the percolating water (Brouwer and Riezbos 1998). Nitrate was found to be most vulnerable to leaching in that study. Thinning also caused space widening, allowing ample penetration of sunlight to assist decomposition processes that increase C and N stocks in soil. Herdiyanti and Sulistyawati (2010) have reported increased C stocks in soil in *A. mangium* plantation which underwent thinning.

The natural forest plot (P1) showed significantly higher content of available P compared to P2 and P5, similar to studies conducted by Chauhan *et al*. (2008). The occurrence of P removal in P2 and P5 were related to fixation in biomass or plant residues from earlier wood harvesting activities (Nykvist and Sim 2009). The loss of P in these plots may also have been due to P fixation in the soil (Zaharah and Sharifuddin 1979) and leaching (Tiessen 1998) in highly weathered tropical soils. All the plots showed very low available P content in our study, similar to results reported by Amir Husni (1983), that is, in the range of 1.5 to 3 mg $kg^{-1}$ in Kemasul Forest Reserve. The low P availability correlates with the acidic pH found in Kemasul Forest Reserve, which is fairly common for tropical forest soils (Fisher and Binkley 2000). Another possible factor could be due to the direct transfer of P from the soil to *A. mangium* trees via mycorrhizal relationships (Mosse 1981). Hence, the various factors that controlled P removal overshadowed the possibilities of P residual from previous fertilization.

*Litter Chemical Composition*

Most of the values from P2 – P5 showed significant increments for N, P, Ca and K compared to natural forest (P1) for leaf litter composition (Table 3). Calcium was significantly reduced to 60 % in the first rotation of more than 20 years and above tree stands (P2) compared to natural forest (P1). Magnesium concentration for P1 was the same as P4 and both were significantly different compared to P2, P3 and P5. The values of leaf litter for all plots varied from 31-34 % for organic C and approximately 1 % for N, K and Ca. The values were less than 1% for P and Mg.

Elevated levels of N, P, Ca and K for plots which underwent thinning (P3 - P5) were due to the larger amount of organic debris in these plots after thinning

TABLE 3
Chemical composition of litter from natural forest and different age classes of *Acacia mangium* plantation at research site

| Concentration / Site | Org. C | Total N | Total P | Total Ca | Total Mg | Total K |
|---|---|---|---|---|---|---|
| | % | | | | | |
| Natural Forest (P1) | 33.12 ab † (0.50) | 1.09 d (0.01) | 0.02 b (0.01) | 0.99 b (0.01) | 0.28 a (0.05) | 0.21 a (0.02) |
| 1st rotation > 20 years (P2) | 32.40 ab (0.08) | 1.59 b (0.02) | 0.02 b (0.01) | 0.40 d (0.02) | 0.23 b (0.01) | 0.32 a (0.04) |
| 2nd rotation 4 years (P3) | 34.24 a (0.06) | 1.29 c (0.00) | 0.01 c (0.01) | 1.25 a (0.01) | 0.21 c (0.01) | 0.52 a (0.01) |
| 2nd rotation 3-6 months (P4) | 32.38 ab (0.44) | 1.73 a (0.02) | 0.03 a (0.01) | 0.71 c (0.01) | 0.26 a (0.01) | 0.26 a (0.02) |
| 2nd rotation 0-3 months (P5) | 31.38 b (0.92) | 1.31 c (0.01) | 0.02 b (0.01) | 0.72 c (0.02) | 0.23 b (0.01) | 1.17 b (0.57) |

Individual values in columns with the same letters are not significantly different at $p \geq 0.05$ according to Tukey test
† Values in parentheses represent standard error

activities. The higher amount of nutrients in P2 may be related to the accumulation of litter and organic matter in the 20 years. The availability of these nutrients is also influenced by temperature, precipitation, litter quality, carbon content and soil microbes (Roig *et al.* 2005) in each plot. Lower levels of Ca in P2 were also reported by Nykvist (1998) due to the uptake and storage of Ca in biomass of tree stands over the years. Magnesium levels were unusually high in P1 and P4 and this could be due the inherent properties of leaf litter in the respective plots. However, our results concur with Wan Rasidah *et al.* (1998) for N, P, and Mg in 4 year old *A. mangium* stands.

Thinning practices in *Acacia mangium* plantation increases carbon and nitrogen stocks in the soil (Jeyanny et al. 2009; Tian et al. 2010). Thinning may reduce possible competition between tree roots and saprophytic microorganisms for water and nutrients and simultaneously enhance mineralisation (Vesterdal *et al*. 1995) of these nutrients. However, this activity may also relatively reduce the availability of P. In order to maintain good and healthy stands, P fertilizer applications may be carried out to replenish the soil nutrient status of the plantation.

The increased concentration of nutrients (N, P, Ca and K) in the litter from the thinned plots and the 1st rotation plot serve as a nutrient reservoir that can slowly incorporate into the mineral soil by decomposition process to enhance plant productivity for the subsequent cycle (Swift *et al.* 1979).

## CONCLUSION

The impact of thinning on soil chemical properties, especially C and N, can only be significantly seen for the top soil (0 - 10 cm). Carbon and N are correlated to leaf litter which encompasses the soil organic matter. Thinning significantly enhanced soil C and N in the 2nd rotation *A. mangium* in 0 - 3 month and 3 - 6 month-old seedlings compared to the other plots. Generally, low levels of P were found in the 1st rotation *Acacia mangium* of more than 20-year-old stands and in plots which underwent thinning. Soil C, N, P decreased with increasing soil depths. The loss of Ca content (litter) in more than 20-year-old stands was significantly lower compared to other plots and the concentration of N, P and K were higher in leaf litter of thinned plots and more than 20-year-old stands compared to natural forest. Plots which underwent thinning showed elevated levels of N, P, K and Ca due to the larger amount of organic debris in these plots after thinning activities.

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