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Leaf Litter Decomposition and Nutrient Release of Three Native Tree Species in a Drained Tropical Peatland in Riau, Indonesia

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ABSTRACT

The decomposition and its nutrient release were the key ecological process that had a broad role in the forest ecosystem. This study aimed to investigate the leaf litter decomposition rate and its nutrient release of three native tree species of tropical peat swamp forest, namely *Macaranga pruinosa, Macaranga gigantea,* and *Cratoxylum arborescens* and one exotic species i.e *Acacia crassicarpa*. The decomposition and nutrient release were monitored in an experimental plot using litter bag technique. The initial litter quality of each litter and micro-environment properties were also observed. The result showed that the decomposition and its nutrient release were insignificantly different among native tree species and also between native species and *Acacia crasssicarpa*. The litter decomposition of all tree species was slow; with the range of k was 0.98-1.19 year^{-1}. However, the P and K release from the decomposition of native species litter after four months of incubation were quickly, ranging 70-74% and 88-93%. We were suggested that the high of lignin content in the leaf litter (36-39%) was the main factor that made slow decomposition. These findings could be used as one of the tools in tree species selection for peat swamp forest rehabilitation.

1. Introduction

The degradation of peat swamp forests (PSFs) in Indonesia is in serious rate. For instance, the remain of pristine PSFs in two largest area of PSFs in Indonesia (Kalimantan and Sumatra) was less than 4%, while the area of PSF with varying degree of degradation was remain 37% (Miettinen and Liew 2010). This fact was often connected to the disaster of fire and hazes which had significant impact on economic value. As the example, the economic losing value due to fire and haze disaster of peat land in Indonesia at 2013 and 2019 were USD 1.49 billion and USD 5.2 billion, respectively (Gultom *et al.* 2016; Worldbank 2019). Furthermore, another impact of this disaster in regional and global level is greenhouse gasses release (especially CO_2) which drives climate change. Carbon emission from peat fire in Indonesia is relatively high, which was in 2015 only could reach about 0.002 Gtonnes (Setyawati and Suwarsono 2018). Totally, the Indonesia's peat fire contribution to global carbon and methane emission were 8 and 23 percent (Charles 2019).

Degradation and deforestation of PSFs in Indonesia must be halted by increasing the rehabilitation through tree plantation activity. The use of native tree species in peatland rehabilitation can be promoted due to some previous studies showed a lot of benefits, particularly in biodiversity and ecosystem service term (Löf *et al.* 2019; Nurulita *et al.* 2016).

We selected three native tree species of PSFs with local name mahang (*Macaranga pruinosa*), skubung (*Macaranga gigantea*) and geronggang (*Cratoxylum arborescens*) for the deeper evaluation in purpose for peatland restoration. Those native tree are pioneer species which naturally occurred in peat forest and had better survivorship than an exotic tree species namely *Acacia crassicarpa* (Suhartati *et al.* 2012; Junaedi 2018). However, generally little was known about the species traits, thus to promote those species for peatland rehabilitation or other purpose more scientific information is required.

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Present study focused to understand the leaf litter decomposition and its nutrient release of the three native tree species as the important ecological indexes. It was well known that its understanding is important due to decomposition is a key ecological process that has broad role in forest ecosystem such as ecosystem sustainability and productivity, carbon and nutrient cycling, soil process and properties; diversity and stability of ecological community and forest regeneration (Versini *et al.* 2014; Das and Mondal 2016; Penner and Frank 2019). Indeed, it was suggested that 30–60% of annual nutrients requirement of tree in forest was provided by this ecological process (Boyle 2005). Moreover, little is known about the litter decomposition insight of native tree species of PSFs, thus this study also will be useful to reduce this gap.

Litter decomposition is controlled by some factors such as litter chemical composition (litter quality), climate, nutrient availability, composition of soil organisms and site-specific factors (Berg and Mcclaugherty 2014; Penner and Frank 2019). Among those factors, the difference of tree species can make the difference on litter quality, nutrient availability and site-specific factors (Aponte *et al.* 2012; Wright *et al.* 2013; Peng *et al.* 2019). For more detail, it was important to study the relationship between the litter decomposition and litter quality and also micro-site characteristic under stands (soil properties and microclimate). Therefore, the aims of the study were: (1) to investigate chemical component (litter quality) in initial leaf litter of the three native tree species, (2) to investigate micro-environment properties under the three native tree species and (3) to explore leaf litter decomposition and its nutrient release of the three native tree species associated with litter quality and micro-environment.

2. Materials and Methods

2.1. Study Site

The study was conducted in an experimental plot; located in a community forest at Lubuk Ogong Village, Pelalawan District, Riau Province, Indonesia (101°41'06"-101°41'10"E, 0°19'42"-0°19'48"N, elevation of 12 m asl). The study site is characterized by a equatorial climate or type A based on Schmidt-Ferguson system, with the range of daily temperature was 21–32°C and mean annual rain fall was 2,500–3,000 mm; a peat soil (histosol) with maturity was dominated by fibric-hemic;and has been drained with the depth of water table variation was 20-135 cm (Husnain *et al.* 2014; Husnain *et al.* 2017; Junaedi 2018).

2.2. Litter Decomposition Experiment

In the beginning, the experiment plot was established in purpose to observe the growth performance of three native tree species of peatland. Tree species was the single treatment in this experimental plot, which was consisted of four species. These tree species consist of three native species/NS (*Macaranga pruinosa*/mahang, *Cratoxylum arborescens*/geronggang, and *Macaranga gigantea*/skubung) and as the comparison also including one exotic tree species (*Acacia crassicarpa*/krassikarpa). All species were planted in similar spacing (2 x 3 m). The plantation was arranged in the field based on a randomized complete block design with five replications, thus each species had five subplots or 20 subplots in total (4 species x 5 replication). Detailed information about this plot experiment also can be seen in (Junaedi 2018). Followed this experimental design; the study of decomposition was done during six months, when the tree age was about 2.5–3 years old. The data of growth average for all studied species at 2.5 years old is shown in Table 1.

The decomposition rate and nutrient release were measured via litter bag technique. The measurement only focused to leaf litter, but it was representative due to the fraction of leaf litter mass in all studied species were dominant i.e. more than 89% (Junaedi *et al.* 2020). Litters from all studied species were collected as freshly fallen leaves and straw from the peat surface (Guo *et al.* 2019). Most of the collected litter then oven dried for about 48 h at 70°C (until constant weight). The leaf litters of each individual species were mixed to obtain a uniform mixture prior being placed in the litterbags. Twenty grams of oven dried leaf litter of all the species then placed to the 25 x 25 cm nylon plastic bag with about 2.0 mm mesh. However, for the litter of skubung, litter must be cutted in to smaller pieces before being placed in the litterbags due to had size that bigger than litterbag size (Hoyos-Santillan *et al.* 2015).

Partly of the collected litter was send to the Laboratory of soil and plant SEAMEO-BIOTROP and Laboratory of woodchemistry, Faculty of Forestry, UGM for analyses the chemycal content of initial litter. These analyses were runned for content of total organic C (Walkey and Black method); total N (Kjeldahl method), total P and K (extract method HCl 25%); water-soluble organic matter/WSOM (ASTM

Table 1. The growth characteristics of all studied species at 2.5 years old (Junaedi 2018)

Tree Species	Survivorship (%)	Height (m)	DBH (cm)
Mahang (*Macarangapruinosa*)	91.2±3.35	5.8±0.30	6.6±0.61
Skubung (*Macarangagigantea*)	68.8±16.83	3.3±0.55	5.5±0.40
Geronggang (*Cratoxylumarborescens*)	88.8±3.35	5.7±0.34	6.4±0.25
Krassikarpa (*Acacia crassicarpa*)	64.8±14.81	13.8±1.03	14.0±0.80

D-1110-1984 method), cellulose (ASTM-D1103-1984 method), lignin (ASTM-D-1106-1984 method) and polyphenol (Folin-Ciolcateu method).

Litterbags of each studied species were distributed to the field according to experimental design that was established. Five litterbags were placed at forest floor (under the stand) for each subplot, thus in total there were 100 litterbags (5 litterbags x 20 subplots) that was deployed. One Litterbag in each subplot was collected five times i.e. after one, two, three, four and six incubation months (Dale *et al.* 2015; Das and Mondal 2016). In laboratory, litterbags were cleaned to remove exogenous materials and then be weighed after oven drying at 70°C 48 h. In order to calculate nutrient release of leaf litter decomposition, nutrient content (N, P, and K) in litters that was collected after four incubation months were analyzed in Soil and Plant laboratory of Research Division of PT. Sarana Inti Pratama (SAIN) in Pekanbaru, Riau. Total N content was analyzed with Kjeldahl method, while total P and K were extracted with 25% HCl.

2.3. Micro-Environment around Litter

Soil samples were collected when the age of all tree species were 2.5 years old using a hoe under each tree species for a depth about 0–20 cm. Samples were collected from five points under each tree and combined to obtain a composite sample. This work was undertaken in three replications for each species, thus each tree species has three composite soil samples (12 composite soil samples in total). Samples were sealed in plastic bags and transported to the laboratory. The soil samples were analyzed in the laboratory of SAIN Pekanbaru, Riau. The analyses included pH using pH meter, total C using colorimeter method, total N using Kjeldahl method, available P using Bray II method, base cations (K, Mg, Ca, and Na) and cation exchange capacity using NH_4OAc (pH 7.0) extraction method.

Due to the limitedness of cost and man power, microclimate around litter was measured only in two times, i.e. in relatively dry season (September 2013) and relatively wet season (November 2013). The observation chosen two variables which was suggested as the most important of litter decomposition determinant in local scale, i.e. temperature and moisture around litter (Petraglia *et al.* 2019). Litter temperature (LM), litter moisture (LM) and below litter temperature (BLT) were monitored hourly during 08.00 AM–16.00 PM. Temperature and moisture were observed by portable temperature and moisture probe.

2.4. The Calculations of Decomposition and Nutrient Release Rate

The litterbags of mahang and geronggang at six months after incubation were incomplete and lead to the miss data. Based on the method in (Attignon *et al.* 2004), the missing data were filled prior to calculate. The remaining mass of litter, decomposition rate and nutrients release then becalculated. The remaining mass of litter was expressed in percentage of initial litter mass. Decomposition rate was expressed by the percentage of mass loss and theconstant of decay rate (k) was calculated using the equation that was given by (Olson 1963) and (Berg and Mcclaugherty 2014): $W_t = Wo.e^{-kt}$, where W_o and W_t are the initial and remaining (at time t) weight of oven-dry leaves respectively; t is the elapsedtime (year); e is the base of natural logarithm and k is the decay constant (years^{-1}). Theestimation of time periods to 50% and 95% litter mass loss (t_{50} and t_{95}) were calculated with equation: $t_{50} = 0.693/k$ and $t_{95} = 2.9957/k$ (Lalramliani *et al.* 2016). Furthermore, nutrient release rate (Nr) from leaf decomposition was calculated using the equation: $Nr = ((W_0.N_0) - (W_t.N_t))/(W_0.N_0)$ (Peng *et al.* 2019); where W_0 and N_0 are the initial litter dry mass and the initial concentration of N, P or K in litter, respectively; W_t and N_t are the litter dry mass after t months incubation and the concentration of N, P or K in litter after t months incubation.

2.5. Data Analysis

The data of litter mass loss, k and rate of immobilized N were inhomogeneous therefore must be transformed to the log (x + 1), log (x+1) and $x^{0.25}$ form (respectively), prior to analysis. One way analysis of variance (ANOVA) was performed to identify the difference of: chemical composition of initial leaf litter, soil properties, microclimate, percentage of mass loss, k, t_{50}, t_{95} and Nr. When the result of the ANOVA was significant, Duncan's multiple range tests was used to determine significant difference between pairs of tree species treatments. Pearson correlation and linear regression analysis were performed to assess the effect

Table 2. The chemical composition in initial leaf litter of the studied species

Variables (units)	Mahang	Geronggang	Skubung	Krassikarpa
Total C (%)	37.49±0.51[b]	33.87±0.19[a]	38.43±0.47[b]	34.92±0.13[a]
Total N (%)	0.94±0.01[ab]	0.93±0.02[ab]	0.99±0.02[b]	0.89±0.01[a]
Total P (%)	0.14±0.01[a]	0.17±0.00[a]	0.14±0.00[a]	0.14±0.01[a]
Total K (%)	0.85±0.00[a]	0.88±0.01[a]	1.01±0.02[b]	0.89±0.01[a]
C/N	39.78±0.48[a]	36.48±0.61[a]	39.02±1.39[a]	39.40±0.62[a]
Water-soluble organic matter (%)	19.17±1.88[a]	15.81±0.38[a]	14.63±0.88[a]	16.60±0.27[a]
Cellulose (%)	32.85±3.61[a]	36.69±0.50[a]	39.26±0.16[a]	47.96±1.19[b]
Polyphenols (mg GAE/g dry weight)	2.57±0.43[b]	0.83±0.26[a]	1.30±0.61[ab]	0.50±0.06[a]
Lignin (%)	36.12±0.84[a]	38.23±0.42[a]	39.23±1.46[a]	33.83±2.25[a]
Lignin/N	38.29±0.86[a]	41.12±0.22[a]	39.84±2.09[a]	38.19±2.78[a]

Means within the same row followed by the different letters are significantly different (p <0.05)

Table 3. Soil properties under the stands of studied species stands at 2.5 years old

Variables (units)	Mahang	Geronggang	Skubung	Krassikarpa
pH H_2O^{ns}	2.96±0.07	2.96±0.07	2.93±0.07	3.07±0.07
Total C^{ns} (%)	43.43±0.62	44.07±0.12	43.33±0.65	44.50±0.81
Total N^{ns} (%)	1.65±0.08	1.66±0.07	1.74±0.05	1.75±0.05
C/N^{ns}	26.45±1.28	26.58±1.11	24.89±0.78	25.55±1.20
Available P^{ns} (ppm)	37.86±3.81	30.37±0.99	29.7±4.09	38.97±4.08
Exchangeable Ca^{ns} (me/100 g)	6.81±1.71	6.28±1.32	3.92±1.24	3.64±1.62
Exchangeable Mg^{ns} (me/100 g)	1.67±0.14	2.20±0.30	1.67±0.20	2.19±0.35
Exchangeable K^{s} (me/100 g)	0.44±0.04ab	0.41±0.02b	0.53±0.04a	0.54±0.04a
Exchangeable Na^{ns} (me/100 g)	0.67±0.003	0.62±0.08	0.69±0.05	0.75±0.12
Cation exchange capacity^{ns}(me/100 g)	158.00±4.33	164.33±7.88	150.00±1.53	159.67±2.91

^{s} = Signifcantly different (p <0.05), ^{ns} = not significantly different (p >0.05), means within the same row followed by the different letters are significantly different (p <0.05)

of initial litter quality and micro-environment (soil properties and microclimate) to the decomposition.

3. Results

3.1. Chemical Composition of Initial Leaf Litter

Content of total C in leaf litter of two native species/ NS (mahang and skubung) was significantly higher (p <0.05) than that in the exotic species krassikarpa (ES) and one remain NS (geronggang). The total N content in NS generally was higher than that in ES, but the significant difference (p <0.05) only revealed between skubung and krassikarpa (Table 2). The content of cellulose in ES was significantly higher (p <0.05) than that in all NS, while the content among NS wererelatively similar. Initial litter of Mahang had highest polyphenol, and significantly (p <0.05) higher than that in geronggang and krassikarpa. The content of total P, total K, lignin and water-soluble organic matter (WSOM) among all studied species (SS) were insignificantly (p >0.05) different. C/N and lignin/N quotients in the leaf litter of SS were insignificantly different (p >0.05).

3.2. Micro-Environment

Soil properties generally were insignificantly different (p >0.05) among NS, also between NS and ES (Table 3). The soil under all species has low pH (extremely acid), high total N, low available P and low base cations.

Microclimate around litter was insignificantly varied (p >0.05) under SS stands, except for litter moister in dry season. The moister litter under ES stand was significantly higher (p <0.05) than that under NS. Generally, litter moister in all SS (NS and ES) were relatively high (above 70%), despite in dry season, except in skubung litter (Table 4).

3.3. Litter Decomposition and Its Nutrient Release

Litter mass loss and constants of decay rate (k) after six months of incubation in all SS were insignificantly different (p >0.05) (Table 5, Figure 1A). The range of k of all NS was 0.98-1.19 year^{-1}, while k of ES was 0.98 (Figure 1A). Furthermore, the required time for 50% and 95% decay were fastest in geronggang litter (t_{50} = 0.63 years and t_{95} = 2.71 years), but insignificantly different (p >0.05) than that in other NS and ES (Figure 1B).

After four months of incubation, the percentage of P and K released from decomposition of NS leaf litter reached 70.1-73.8% and 89.5-93.1%, respectively (Figure 2). This P release was insignificantly different among NS, but significantly slower (p >0.05) than

Table 4. Microclimate around litter under studied species stands

	Mahang	Geronggang	Skubung	Krassikarpa
Dry season:				
Litter moister (%)	71.26±10.20[b]	79.78±8.07[b]	56.04±5.33[c]	91.24±7.42[a]
Litter temperature (°C)	29.12±0.84[a]	28.57±0.52[a]	29.03±0.72[a]	28.92±0.73[a]
Below litter temperature (°C)	28.50±0.25[a]	28.40±0.35[a]	28.57±0.68[a]	28.78±0.17[a]
Wet season:				
Litter moister (%)	88.44±0.66[a]	89.41±1.46[a]	87.03±1.55[a]	91.79±1.38[a]
Litter temperature (°C)	27.78±0.26[a]	27.33±0.24[a]	27.98±0.67[a]	28.08±0.19[a]
Below litter temperature (°C)	27.67±0.22[a]	27.30±0.15[a]	27.68±0.34[a]	28.0±0.19[a]

Table 5. Change in litter mass loss (%) over time (months) of studied species

Months after incubation	Mahang	Geronggang	Skubung	Krassikarpa
1	4.75±0.92[b]	4.90±1.24[b]	2.90±1.20[b]	15.2±1.05[a]
2	15.12±1.85[b]	12.95±1.75[b]	6.10±1.30[c]	19.73±1.69[a]
3	20.91±3.15[b]	18.70±1.29[bc]	11.12±2.28[c]	29.92±3.37[a]
4	28.87±4.69[a]	26.00±2.99[a]	14.00±2.56[b]	33.50±3.19[a]
6	41.50±4.12[a]	44.04±5.51[a]	39.75±4.73[a]	39.40±1.87[a]

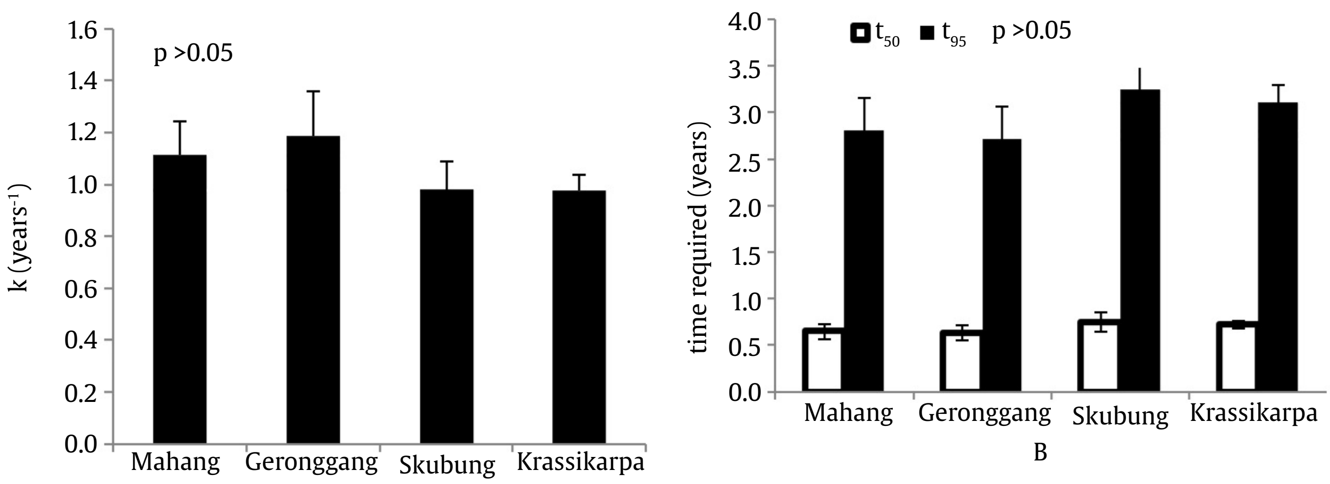

Figure 1. Decomposition rate constants (A) and time required for 50% (t_{50}) and 95% (t_{95}) decomposition (B) in different studied species

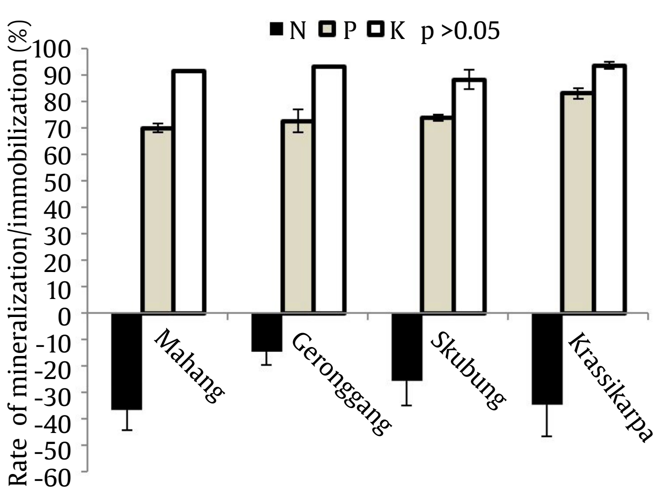

Figure 2. The percentage of N immobilization, P and K released from leaf litter decomposition after four months incubation (negative value for immobilization and positive value for mineralization)

that of ES with P release 82.6%. K released was insignificantly different between all NS and ES (Figure 4). Different with P and K, N in all litters of SS were immobilized. Range of this immobilized N of NS was 14.5-25.6% and insignificantly different ($p > 0.05$) among them and with ES.

3.4. Correlation between Decomposition and Litter Quality and Micro-environment

All variables of litter quality were insignificantly correlated ($p > 0.05$) with decomposition rate (k) (Table 6). The insignificant correlation ($p > 0.05$) also showed by the relationship between all variable of micro-environment and k (Table 7).

Table 6. Correlation coefficients between k and chemical composition of initial litter (p >0.05)

	C	N	P	K	C/N	WSOM	Cellulose	Polyphenol	Lignin	Lignin/N
k (year[1])	-0.45	0.55	0.21	0.46	0.05	0.52	-0.13	0.08	-0.01	0.36

Table 7. Correlation coefficients between k and micro-environment (p >0.05)

	pH	C	N	C/N	P	K	Ca	Mg	Na	CEC	LM	LT	BLT
k (year[1])	-0.39	0.08	-0.3	0.27	-0.1	-0.18	-0.44	0.31	0.18	-0.08	0.28	-0.47	-0.27

4. Discussion

4.1. Litter Quality

This study showed that some variables of initial litter chemistry of studied species (SS) which was consist of three native species/NS (mahang, geronggang and skubung) and one exotic species/ES (krassikarpa) were significantly different (p <0.05). However, in general all SS had similar litter quality, based on the magnitude of total N, total P, lignin, C/N, Lignin/N. The litter quality of all SS were low due to had content of N <2.5%, P <0.25%, C/N >30 and lignin> 28% (Prescott 2005; Boyd 2009; Partey *et al.* 2011).

Based on some previous studies, the comparison of nutrient content in the initial litter between NS and some other tree species of tropical forest presented different results, depending on the elements. Total K and P in the litter of all NS were higher than those in litter of *Koompassia malaccensis, Shorea uliginosa,* and mixed tropical peat forest tree species (Sulistiyanto *et al.* 2005; Ong *et al.* 2017). However, leaf litter of all NS in present study in general had lower N content than that in most of native species of tropical peat swamp forest, despite its value was in the range (0.8–1.78) (Sulistiyanto *et al.* 2005; Ong *et al.* 2017; Ichie *et al.* 2019)

Lignin content in the litter of all NS in present study (36.1-39.2%) was higher than that in the range of content lignin in other native tree species of peat swamp forest (3.8-35.8%) (Hoyos-Santillan *et al.* 2015; Ichie *et al.* 2019) also than that in the average of broadleaves (29.26%) and coniferous (21.57%) (Rahman *et al.* 2013). In different ecosystem with wider scale, lignin content of leaf litter of beech (36%) in temperate forest were the closest to lignin content in the NS (Kara *et al.* 2014). For polyphenol, the content in NS litter was less than that in some macaranga species litter (Lim *et al.* 2014).

4.2. Micro-environment for Decomposition

We observed the soil properties after 2.5 years of the plantation of the three NS and one ES. For the peatland ecosystem, the soil properties under 2.5 years old of NS was similar to soil properties of critically degraded peatland, drained forest peatland, agricultural peatland, peat forest that was convert to oil palm and *Acacia* spp. estate (Husnain *et al.* 2017; Yondra and Wawan 2017; Agus *et al.* 2020). At the tropical ecosystem, lower temperature and higher moister is better microclimate for decomposition. Therefore, the microclimate under NS in this study was better than that in agriculture peatland, similar to drained degraded and re-growing forest, but not better yet than that in natural peat swamp forest (Astiani *et al.* 2017; Jaya *et al.* 2018).

4.3. Rate of Decomposition and Its Nutrient Release

Decomposition rate of leaf litter of all NS in present study was slow (k <1.8 and t_{50} >0.4 years), based on the classification of (Petersen and Cummins 1974), but it was higher than that of other tree species of tropical peat swamp forest (0.25–0.81) (Table 8). This slow decomposition confirmed that the decomposition of leaf litter of native tree species in tropical PSFs was relatively retarded. However, this phenomenon could not be generalized yet for all native tree species of PSFs, due to the decomposition studies in present and several previous studies were done in the pioneer species. Therefore, in term for whole native species of PSFs further research in non-pioneer tree species is required.

In term of decomposition in tropical tree species; the decomposition rate of all NS was relatively comparable with that of *Acacia mangium* and *A. auriculiformis* in Mount Forest; lower than that of teak, *Acacia nilotica*

Table 8. Decomposition rate constant (k) across tropical tree species

Species	k (year^{-1})	Site	References
Campnosperm acoriaceum	0.50	Tropical peat swamp forest, Malaysia	(Yule and Gomez 2009)
Mixed species	0.60-0.81	Mixed and low pole swamp forest, Kalimantan, Indonesia	(Sulistiyanto *et al.* 2005)
Calophyllum canum, Combretocarphus rotundatus and *Cratoxylum glaucum*	0.25-0.62	Natural and post fire peat swamp forest, Kalimantan, Indonesia	(Rahajoe *et al.*2005)
Macaranga spp., *Shorea* spp., *Artocarpus* spp., *Dipterocarpus geniculatus*	0.38-2.36	Tropical rain forest, Serawak, Malaysia	(Hirobe *et al.* 2004)
Rhizophora racemosa, R. mucronata, R. apiculata and *Avicennia marina*	1.64-4.5	Mangrove forest in Aceh, Banten, Indonesia and Costa Rica	(Dewiyanti *et al.* 2019; Loría-Naranjo *et al.* 2019; Siska *et al.* 2016)
Juniperusprocera, Oleaeuropaea and *Carissa edulis*	0.09-0.24	Dry Afromontane forest, Ethiopia	(Birhane *et al.* 2019)
Acacia mangium and *A. auriculiformis*	1.12-1.27	Mount makiling forest, South Central Luzon, Philippines	(Lee and Woo 2012)
Teak, Acacia nilotica, Eucalyptus sp.	1.7-3.0	Coromandel Coast, Puducherry, India	(Swarnalatha and Reddy 2011)
Pinus massoniana	0.80	Pioneer masson pine forest, tropical forest, Shouthern China	(Chen *et al.* 2014)

and *Eucalyptus* sp. in Coromandel coast and also than that of mangrove tree species in Indonesia and Costa Rica; higher than that of dry afromontane tree species and *Pinus massoniana* in Pioneer masson pine forest; and within the litter decomposition rate range of tropical rain and wet forest tree species (Table 8).

Despite the decomposition rate of all NS was retarded, but after 4 month incubation, the release of P (>70%,) and K (>80%) from leaf litter decomposition were fast. The relatively fast of P and K release in present study was suggested relate to the moist condition of litter during the study period. As the result showed before, litter of all SS had high moister during decomposition study. Moist environment is the ideal condition for leach and decay P and K of litter. Litter P in $PO4^{-3}$ form was eased to decay and leach (Haitao *et al.* 2007), while K is the most mobile element, exist in ionic form and relatively not associated with plant structure thus was easiest to remove from litter, particularly by leaching (Berg and Mcclaugherty 2014).

The immobilization of N in all SS was related to the low quality of litter, especially with low N and high C/N quotient. The N content in all SS litters were less than 1% and its N generally was not met with decomposer requirement, and would drive decomposer to acquired N from around environment. This process was expressed by the existing of mycelium on the litter (Figure 4). Furthermore, as shown before, the value of C/N in initial litter of all SS was high and more than 25. This high C/N theoretically could have lead to N immobilization (Pei *et al.* 2019).

4.4. The Influencing Factor on Decomposition

The study did not find the variables of litter quality and microenvironment which had significant correlation ($p < 0.05$) with decomposition rate. As the result, based on correlation analysis only, our study did not found the most influencing factor in decomposition of tree studied species. However, (Prescott 2005) reported that lignin would be the determinant factor of decomposition on the litter that had lignin more than 28%, but the correlation might not be significant due to rate decomposition in studied species was relatively similar in slow rate. This statement met to our study condition, which lignin content in all studied species was similar high (lignin >28%) and decomposition rate in all species also was similar slow. According to those facts, the present study suggested that lignin was the main factor that driven slow decomposition in all SS (NS and ES). For further confirmation of this suggestion, the study collected the couple data of lignin-k from other studies in relatively wider variation (Hirobe *et al.* 2004; Aprianis 2011), then combines with the couple lignin-k data in present study for regression analysis. Result of this regression analysis showed that lignin had negative effect on decomposition rate (k), strongly (R2 = 0.65) and significantly ($p < 0.05$), thus supported to the suggestion (Figure 3). Theoretically, this negative effect on decomposition due to the chemical structure of lignin is more complex and heterogeneous lead to not easier to degrade than other chemical component of litter (Jex *et al.* 2014).

Our study was undertaken at drained peatland, thus we suggested that the soil decomposer was not the constraint factor of decomposition. Despite soil microorganism parameter in the study specifically was not observed, the visualization of litter in the field shown the existing of decomposer via the sign in mycelium form (Figure 4). This visualization synchronized with (Yule 2010) who reported that the microorganism in peatland was relatively diverse, including the decomposer organisms.

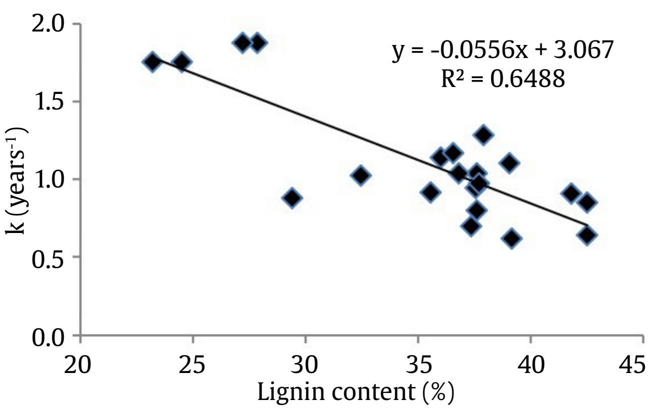

Figure 3. Regression between k and lignin content based on the combination data of present and previous study (Hirobe *et al.* 2004; Aprianis 2011)

In conclusion, all native tree species of *Macaranga pruinosa* ,*Cratoxylum arborescens*, and *Macaranga gigantea* and also the exotic species of *Acacia crassicarpa* had similar litter quality. The litter quality of all studied species were low quality, particularly were expressed by the low P and N content, and also high lignin content. The micro-environment (soil and microclimate) under the stand of all studied species also were similar. These similarities lead the similarities of decomposition and nutrient release rate in all studied species. The decomposition rates of all studied species were slow. However, the nutrient release of P and K were fast release, while N was immobilized. Based on this decomposition trait, the three native species could be classified in one group and also similar with the group of the pioneer species of peat swamp forest and some acacia species. Among factors that can influence the decomposition, the presence of high lignin was the main factor that caused the slow decomposition in all studied species. For the purpose of the establishment of plantation forest which required fertile land in long term, due to nutrient content in litter was low and also N was immobilized, the mixed plantation with other species that had good litter quality or with some N-fixing tree species more recommended. For peatland restoration, the slow decomposition of all native species can act as carbon sink, but could lead to the abundance of litter at peatland surface and has possibility to become fuel. Therefore, for this purpose

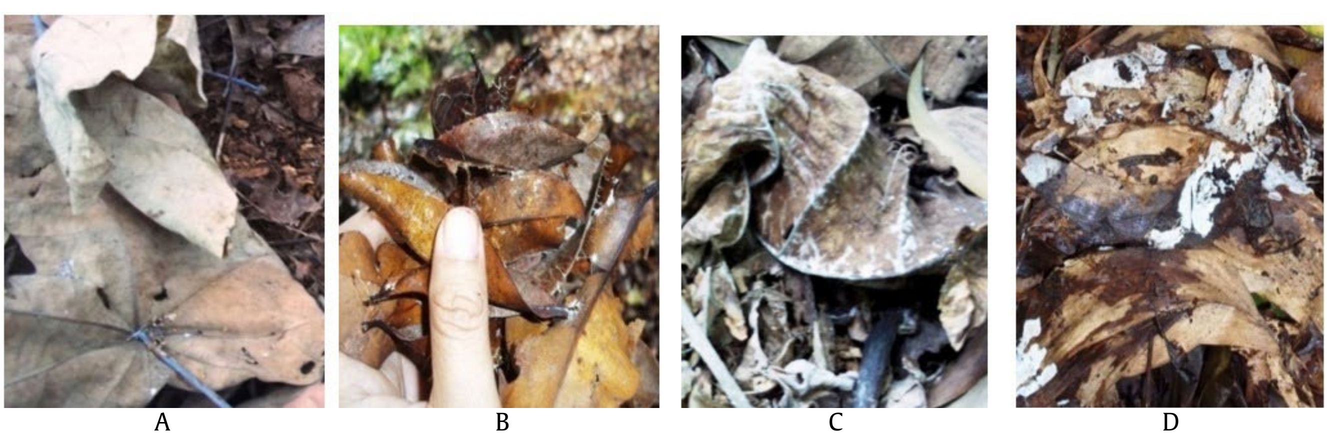

Figure 4. Mycelium on the litter of studied species (A = mahang, B = geronggang, C = skubung, and D = krassikarpa)

the management to maintain tree density, water table and soil/litter moister must be noticed.

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