Nutrient distribution on soil and aboveground biomass of *Macaranga gigantea* five years after planting

DWI SUSANTO[1,♥], RATNA KUSUMA[1], RUDIANTO AMIRTA[2]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Mulawarman University. Jl. Barong Tongkok No. 4, Gunung Kelua, Samarinda Ulu, Samarinda-75123, East Kalimantan, Indonesia. Tel./fax.: +62-541-749140, 749152, 749153, ♥email: susantodwiki@yahoo.com
[2]Faculty of Forestry, Mulawarman University. Jl. Ki Hajar Dewantara, Kampus Gunung Kelua, Samarinda 75123, East Kalimantan, Indonesia

Abstract. *Susanto D, Kusuma R, Amirta R. 2018. Nutrient distribution on soil and aboveground biomass of* Macaranga gigantea *five years after planting. Asian J For 2: 12-19.* Despite the high potentials of *Macaranga gigantea* to be developed as biofuel plantation, there is limited understanding of the growth of this species especially when it is planted as uniform stand and treated with silvicultural application. This research aimed to investigate the growth and accumulation of aboveground biomass of *M. gigantea* in varying fertilization treatments five years after planting, and to evaluate the distribution of nutrients in soil and aboveground biomass. Five treatments at randomized design were established with each treatment having three blocks, and each block contained 20 plants, making 300 plants in total. The five treatments of *M. gigantea* were the application of NPK fertilizer at five measures, i.e.: P0: 0 g, P1: 40 g, P2: 80 g, P3: 120 g and P4: 160 g. Aboveground biomass and nutrient contents of N, P, K, Ca and Mg accumulated the plants were measured across the treatments, while soil sampling was conducted to analyze the nutrients accumulated in the soil. The research findings revealed that treatment P4 had the best growth performance with accumulation of N, P, K, Ca and Mg in wood, bark, branches, and leaves twice as higher than those in treatment P0. The most distributed nutrients in the soil were magnesium, nitrogen, calcium, and phosphorus. Whereas the most accumulated nutrient in plant was potassium. The relative portion of K stored in the soil is quite small (44.18%) while K accumulated in plant was 55.82%. These findings imply that if *M. gigantea* plantation is harvested at five years rotation, it needs to give attention to the availability of potassium nutrients for the next planting cycles.

Keywords: Biomass, *Macaranga gigantea*, distribution nutrient, soil

INTRODUCTION

Macaranga gigantea is a pioneer and fast-growing tree species widely distributed in lowland of tropical rainforest, usually growing within the gaps after shifting cultivation (Susanto et al. 2016b), forest fires (Silk 2008) and timber harvestings (Susanto et al. 2017a). The plant reproduces by forming flower buds initiated in the dry season and the fruits ripened in the rainy season (Bentos et al. 2008).

Because of the rapid growth and high accumulation of biomass, *M. gigantea* has the potentials to be developed as raw source for bioethanol by establishing large-scale plantation forestry (Amirta et al. 2016). So far, only limited number of tree species have been developed as biofuel in the tropical region with several of them are recognized as non-native species. The hindrance of such development is mainly due to the limited understanding of the early growth of *M. gigantea* especially when it is planted as uniform stand compared to when it grows naturally. The lack of knowledge is particularly eminent from the seedling development stage into juvenile age.

The seeds of *M. gigantea* are classified as orthodox seeds and have low water content. The seeds that fell under the tree are germinating in approximately 24 days (Susanto et al. 2016a). Susanto et al. (2016a) reported that wet extraction without fruit drying treatment is able to increase seeds germination to 65%) with germination time first seeds (GTFS) 7.67 ± 1.15 days, germination time last seeds

(GTLS) 17.33 ± 4.04, and mean germination times (MGT) 11.97 ± 1.93 days. However, previous studies demonstrated that additional seed treatments do not necessarily increase germination rate. Using dry seed extraction treatment, the seeds produce low seed germination rate of 2-10% (Suita and Nurhasiby 2009), while soaking the seeds into 0.2% potassium nitrate solution for 20 minutes before germinating on sand medium is only able to increase seed germination rates up to 20% (Mindawati et al. 2010). During the germination stage, *M. gigantea* seedlings showed the highest relative growth rate when planted on mushroom spawn waste media, followed by compost, topsoil, and sand media (Susanto et al. 2016a).

The experimental planting of *M. gigantea* seedlings in the field also showed mixed results. Lawrence (2001) reported that the seedlings of *M. gigantea* grew rapidly over the first of 18 weeks when planted in polybags enough supplied with a combination of nitrogen and phosphorus fertilizers. While, Nussbaum et al. (1995) found that nutritional deficiency is an important factor that inhibits early growth *M. gigantea* at the age 6 months after planting in degraded land of unused log piles in Malaysia.

Susanto et al. (2016b) reported that in secondary forests after shifting cultivation, *M. gigantea* plants accumulated phosphorus and potassium nutrient mostly in the leaves. On the other hand, in secondary forests after selective logging, most accumulated nutrients in *M. gigantea* were potassium, calcium, and magnesium. It suggested that bases nutrients,

potassium, calcium, and magnesium are by *M. gigantea* and extremely important to its growth (Susanto et al. 2017a). In monoculture system, *M. gigantea* was fertilized with NPK at the age of 1 year, the most nutrient element accumulated were potassium, followed by phosphorus and then nitrogen (Susanto et al. 2017b).

There is a lack information about aboveground biomass of *M. gigantea* treated with silvicultural application in relation to nutrient content stored in the soil. This research aimed to investigate the growth and accumulation of aboveground biomass of *M. gigantea* in varying fertilization treatments five years after planting, and to evaluate the distribution of nutrients in soil and aboveground biomass. This information is very important as reference for the development of *M. gigantea* plantation.

MATERIALS AND METHODS

Experimental site description
This research was conducted at the research forest of Faculty of Forestry, Mulawarman University, Samarinda, East Kalimantan, Indonesia (000.44.71,11" South and 1170.21; 67,50" East). The experimental plot had an extent of 0.7 ha, consisting planting trial of *M. gigantea* at the age of 5 years old. The trial was set up with five randomized treatments plots, each treatment had three blocks, and each block contained 20 plants, making 20 x 5 x 3 = 300 plants in total. The five treatments of *M. gigantea* were the application of NPK fertilizer at five measures, i.e.: P0: 0 g, P1: 40 g,

P2: 80 g, P3: 120 g and P4: 160 g. Fertilization was conducted two times, i.e., directly after planting and 6 months after planting. Weed cleaning was done once for 4 months until the plant age was 2 years old (Susanto et al. 2017b).

Procedures
Plant measurement and soil analysis
The samples of the five-year-old *M. gigantea* were observed through direct measurement. The stem heights, diameter, height increment and diameter increment were the parameters in this research. For soil analysis, soil samples were taken at a depth of 0-30 cm and 30-60 cm at each plot. Soil analysis was conducted after the samples were oven-dried with a temperature of 150ºC until the weight was constant. Composite sample was wind-dried and its total Nitrogen (Kjeldahl), available phosphorus (Bray), available potassium, calcium, and magnesium were analyzed (Susanto et al. 2017b).

Measuring Macaranga gigantea *biomass*
Biomass measurements were limited only to aboveground biomass of the average tree after stratification method. The determination of strata boundaries for sample selection was performed using cumulative method. The trees sampled from one plot were selected after all the available trees were grouped into three stages based on their estimated size according to the formula D^2H (diameter squared multiplied by height).
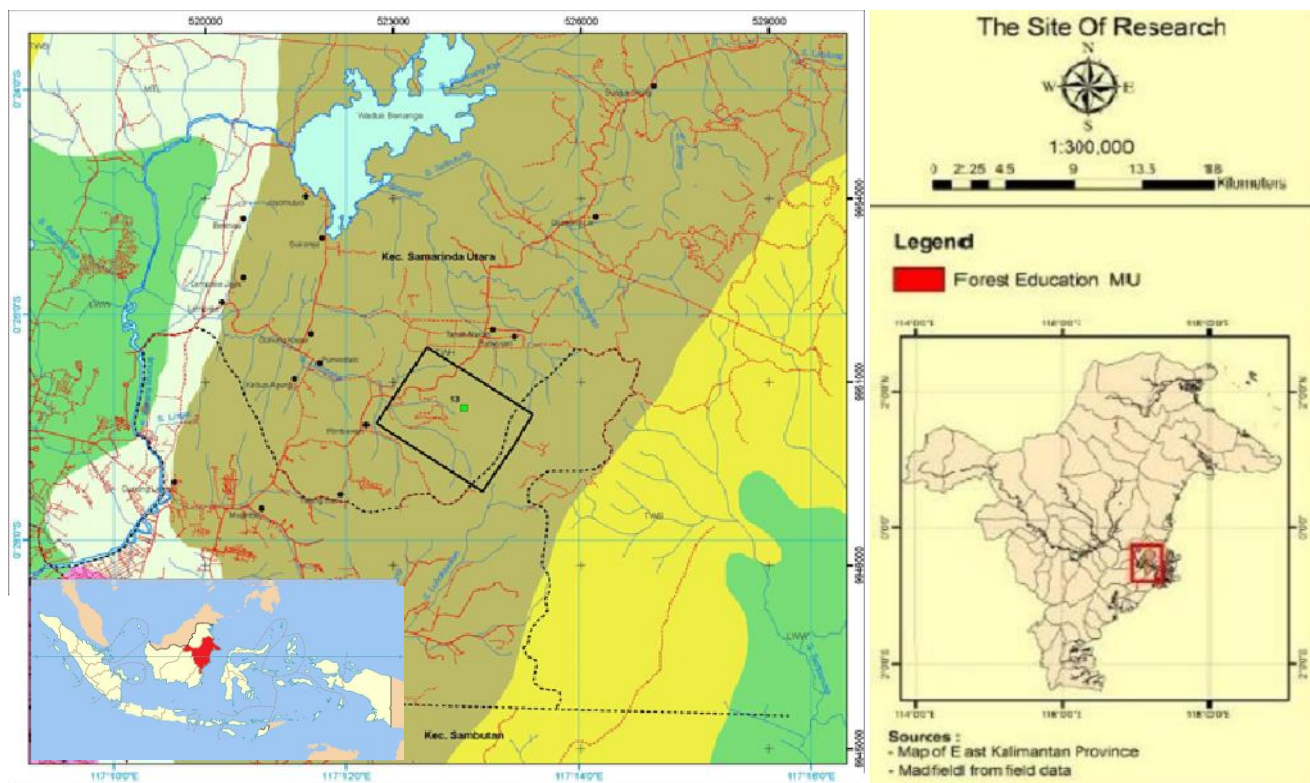
Figure 1. Map of the experimental site in the research forest of Faculty of Forestry, Mulawarman University, Samarinda, East Kalimantan, Indonesia

The entire stand biomass was calculated by multiplying the dry weight of the components of the sampled tree by the number of trees in each stage, and then it was converted into a biomass per hectare. The wet weight of every component including wood, barks, branch, and leaves was measured according to Ruhiyat (1996) methods. Samples of the wood, barks, branch, and leaves were weighed in wet and dry condition. The plant samples were taken to the laboratory and their nutrient contents (N, P, K, Ca, Mg) were analyzed.

Measuring nutrients in plant

The total N concentration was measured using Kjeldahl method (extraction, distillation, titration). To measure element of P and K, the plant components were extracted using High-Pressure Digestion method at the temperature of 180°C for 10 hours with HNO3 as a reductant. Phosphorus was measured by calorimetric technique using nitrate-molybdate-vanadate acid as a coloring agent, and was measured using spectrophotometer at the wavelength of 470 nm. Potassium, calcium, and magnesium were measured using Atomic Absorption Spectrophotometer at the wavelength of 766.5 nm, 489.5 nm, and 245.2 nm. To calculate macronutrient elements (N, P, K, Ca, Mg) that were accumulated in the three components in the stand, the dry weight of the tree component was multiplied by its nutrient concentration (Susanto et al. 2017b).

Data analysis

Nutrient distribution in soil and in the *M. gigantea* plants at the five-year-old was observed. The content of macronutrients (N, P, K, Ca, Mg) in the plant parts were calculated by multiplying the dry weight of the part with nutrient concentration. Based on the nutrients stored in the soil and the nutrient accumulated in the *M. gigantea* stands, it can be obtained information about the number of nutrients stored in the soil (kg.ha-1) and its relative portion (%) accumulated in the plant.

RESULTS AND DISCUSSION

Plant growth

At the age of 5 years, the best growth of *M. gigantea* is shown by the treatment P4 with mean stem diameter of 12.88 ± 4.2 cm, stem height of $10.25 \pm 2,9$ m, increment diameter 2.58 cm.y^{-1} and hight increment 2.05 m.y^{-1} (Figure 2).
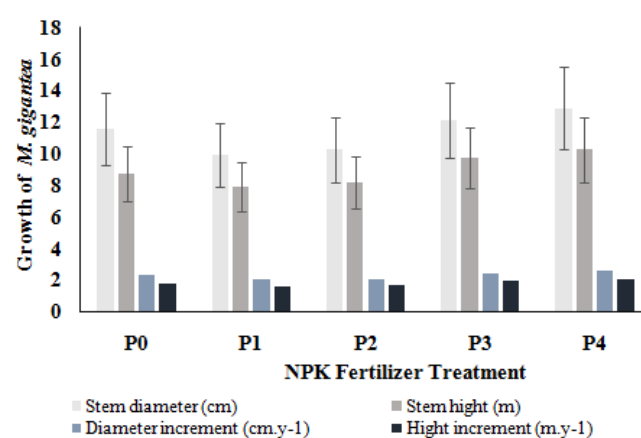
Figure 2. The growth parameters of *Macaranga gigantea* across five different treatments at the age of five years old.

Figure 3. The stand of *Macaranga gigantea* plants at planting plots at the age of five years

Plant biomass

The result on aboveground biomass estimation of *M. gigantea* showed that the highest biomass was produced by treatment P4 with 64.51 ton.ha^{-1}, comprising 27.58 tons stored in main stem, 5.078 tons in bark, 22.938 tons in branch (wood and bark), and 8.914 tons in leaves. Woody biomass had the largest biomass component with 50.52 ton.ha^{-1}, consisting of 27.58 tons stored in the stem and 22.938 tons in the branches. The lowest biomass was produced by treatment P0 with 25.039 ton.ha^{-1}. Based on this result, it can be concluded that fertilization of 160 g per plant (P4) increases biomass production by 250 percent.

Nutrient content in plant components

Potassium was the most accumulated nutrient in the five-year-old stands, followed by nitrogen, calcium, phosphorus, and magnesium. The amount of nutrients absorbed by *M. gigantea* stands were potassium, ranged from 239.88 to 676.20 kg.ha^{-1} with an average of 413.50 kg.ha^{-1}; calcium, ranged from 66.51 to 114.56 kg.ha^{-1} with an average of 232.62 kg.ha^{-1}; nitrogen, ranged from 155.91 to 344.00 kg.ha^{-1} with an average of 232.62 kg.ha^{-1}; and magnesium, ranged from 36.09 to 77.64 kg.ha^{-1} with an average of 51.93 kg.ha^{-1}. The highest concentration of nitrogen, phosphorus, potassium, calcium and magnesium occurred at treatment P4 with fertilization of NPK at 160 g per tree (Table.1).
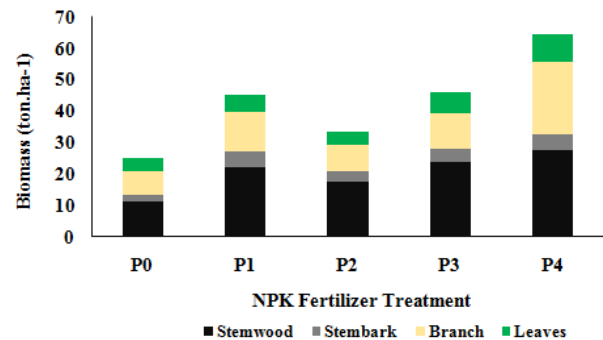
Soil nutrient content

Soil nutrient concentration at treatment plot varied in value. There is an increasing tendency of dosage of NPK fertilizer to decrease soil nutrient concentration at each treatment plot. In terms of N, the highest concentration at the depth of 0-60 cm was at the P2 plot with 13405.4 kg.ha^{-1}, followed by the P1 plot with 12744.5 kg.ha^{-1}, P3 plot with 12210.7 kg.ha^{-1}, plot P0 with 12136.5 kg.ha^{-1} and the lowest was at plot P4 with 10888.7 kg.ha^{-1}. In terms of P, the highest concentration at the depth of 0-60 cm was at the plot P0 with 441.3 kg.ha^{-1}, followed by plot P1 with 435.4 kg.ha^{-1}, plot P2 with 386.5 kg. ha^{-1}, plot P4 with 377.4 kg.ha^{-1} and the lowest was at plot P3 with 291.8 kg.ha^{-1}. The highest K nutrient occurred at plot P0 with 1034.2 kg.ha^{-1}, followed by plot P2 with 603.7 kg.ha^{-1}, plot P1 with 573.9 kg.ha^{-1}, plot P4 with 535.2 kg.ha^{-1} and the lowest was at plot P3 with 448.8 kg.ha^{-1}. The highest Ca occurred at plot P0 with 26953 kg.ha^{-1}, followed by plot P1 with 26232 kg.ha^{-1}, plot P3 with 25085 kg.ha^{-1}, plot P2 with 23630 kg. ha^{-1} and the lowest was at plot P4 with 21963 kg.ha^{-1}. While the concentration of Mg was the highest at plot P0 with 51292 kg.ha^{-1}, followed by plot P1 with 48111 kg.ha^{-1}, plot P2 with 45603 kg.ha^{-1}, plot P3 with 39800 kg.ha^{-1} and the lowest was at plot P4 with 38520 kg.ha^{-1}.

The nutrient content in *M. gigantea* is positively correlated with biomass production at 5 years of age. The higher the nutrient content of biomass the higher the biomass production (Figure 5). On the other hand, the relationship between soil nutrient content and biomass production shows negative correlation, i.e., the higher the biomass production, the lower nutrient content in the soil

(Figure 6). The same is also shown in the relationship between soil nutrient and nutrient content in plant (Figure 7).

Nutrients stored in the soil and nutrients accumulated in aboveground biomass

The nutrient content stored in the soil and nutrients accumulated in *M. gigantea* is shown in Figure 8.


Figure 4. The distribution of aboveground biomass stored in plant components in *Macaranga gigantea* (five-year-old) across five different treatments.

Table 1. Nutrient content stored in plant components in *Macaranga gigantea* (five-year-old) across five different treatments

| Nutri-ents	Fertilizer appli-cation	Nutrient content of plant components (kg.ha^{-1})				
		Stem wood	Stem bark	Branch	Leaf	Total
N	P0	39.48	13.16	33.81	69.48	155.92
	P1	63.59	24.18	44.05	91.74	223.56
	P2	48.75	21.40	35.50	70.69	176.34
	P3	65.28	23.92	53.96	120.13	263.29
	P4	79.16	24.74	89.54	150.57	344.01
Mean		**59.25**	**21.48**	**51.37**	**100.52**	**232.63**
P	P0	6.08	1.30	7.07	6.46	20.91
	P1	4.94	1.34	3.35	8.17	17.79
	P2	2.16	1.35	5.79	6.95	16.23
	P3	3.47	1.99	8.52	8.53	22.52
	P4	11.72	3.14	14.79	13.39	43.04
Mean		**5.67**	**1.82**	**7.90**	**8.70**	**24.10**
K	P0	69.86	28.80	66.17	75.06	239.89
	P1	165.96	32.47	104.23	97.07	399.72
	P2	57.04	40.48	104.65	86.63	288.79
	P3	144.57	49.58	145.97	122.81	462.93
	P4	198.95	66.95	240.08	170.23	676.20
Mean		**127.28**	**43.66**	**132.22**	**110.36**	**413.51**
Ca	P0	27.08	13.12	14.20	12.11	66.51
	P1	11.78	28.02	20.97	15.06	75.83
	P2	22.36	16.85	11.27	13.07	63.55
	P3	14.91	24.21	20.94	16.59	76.65
	P4	30.47	17.87	40.16	26.07	114.57
Mean		**21.32**	**20.01**	**21.51**	**16.58**	**79.42**
Mg	P0	14.46	4.50	8.318	8.82	36.10
	P1	18.99	11.47	12.66	12.57	55.69
	P2	16.44	6.81	10.79	10.52	44.55
	P3	13.97	6.82	11.18	13.72	45.69
	P4	25.17	8.49	25.80	18.19	77.64
Mean		**17.81**	**7.62**	**13.75**	**12.76**	**51.93**

Note: P0 = control without fertilizer, P1 = NPK fertilizer 40 g, P2 = NPK fertilizer 80 g, P3 = NPK fertilizer 120 g and P4 = NPK fertilizer 160 g.
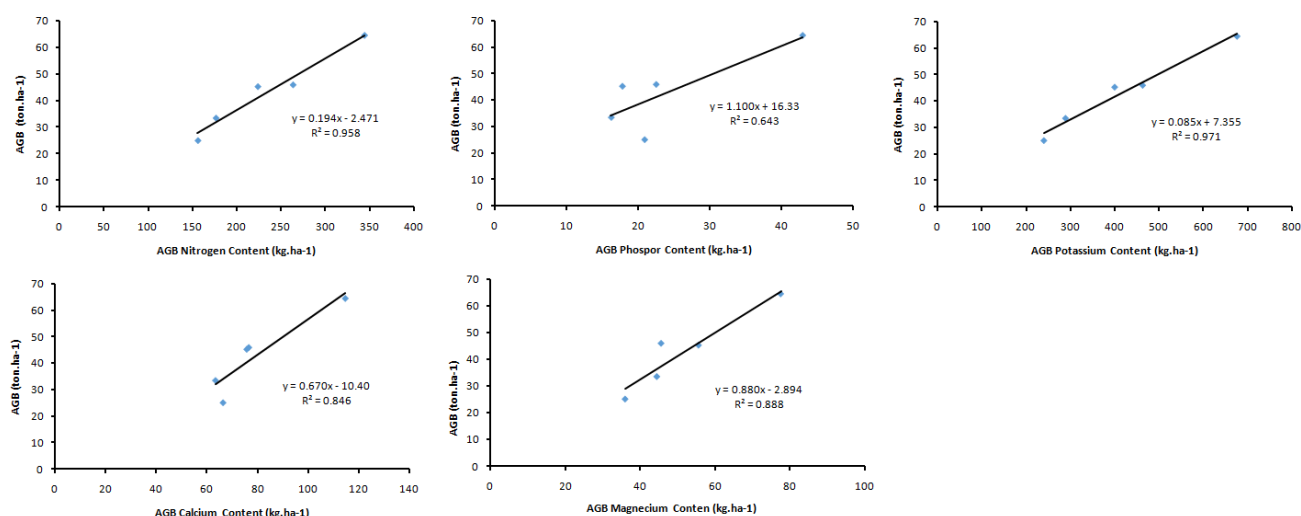
Figure 5. Corelation between aboveground biomassa and nutrient content stored in the plant of *Macaranga gigantea* at five years old
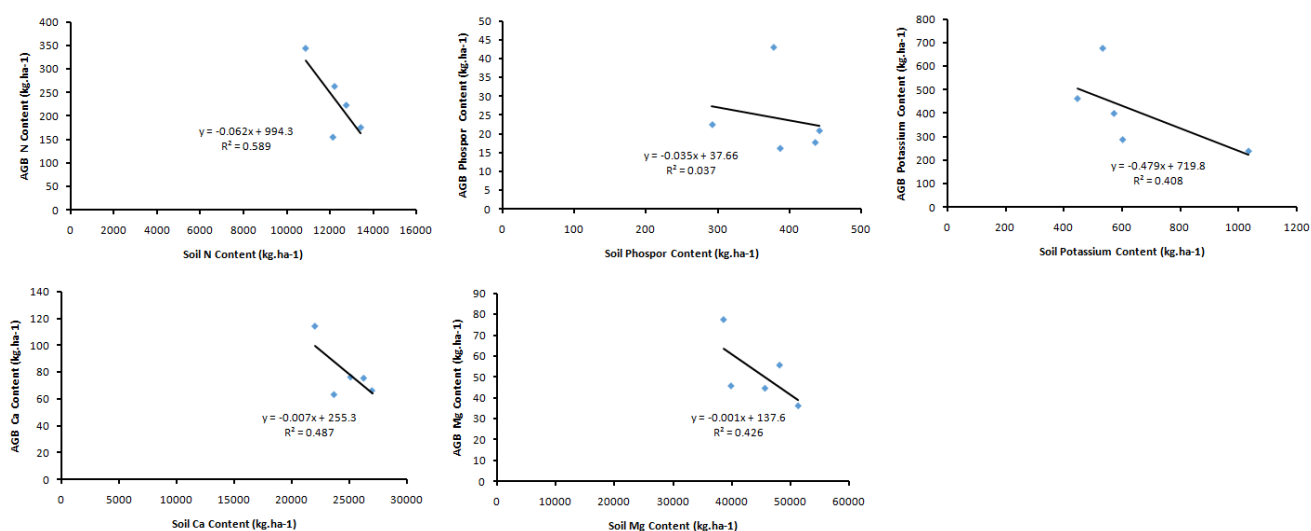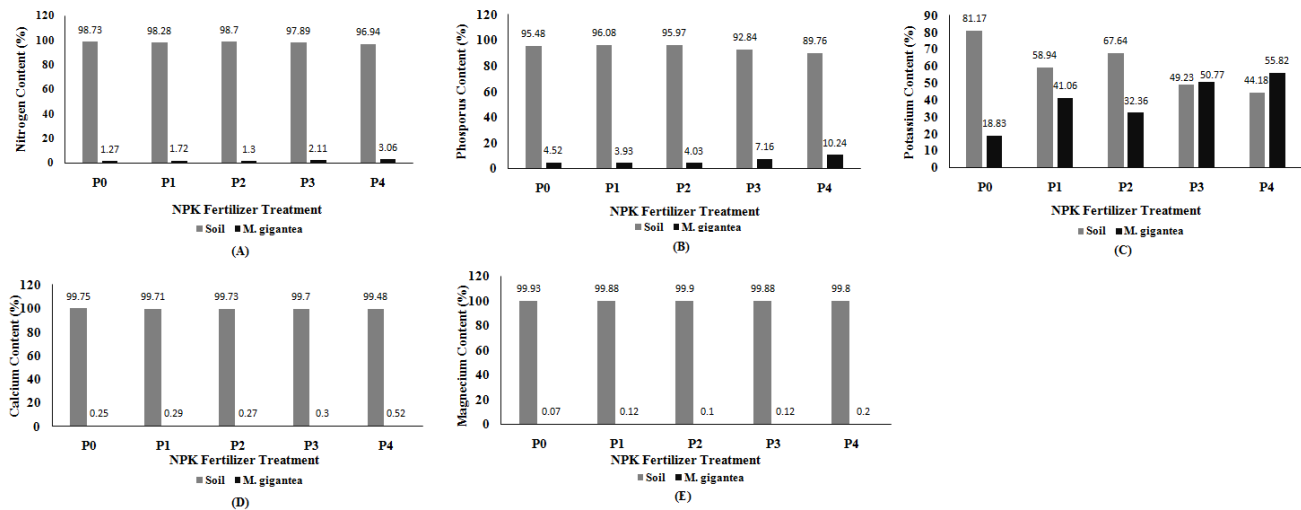

Figure 6. Corelation between soil nutrient and plant nutrient content of *Macaranga gigantea* at five years old
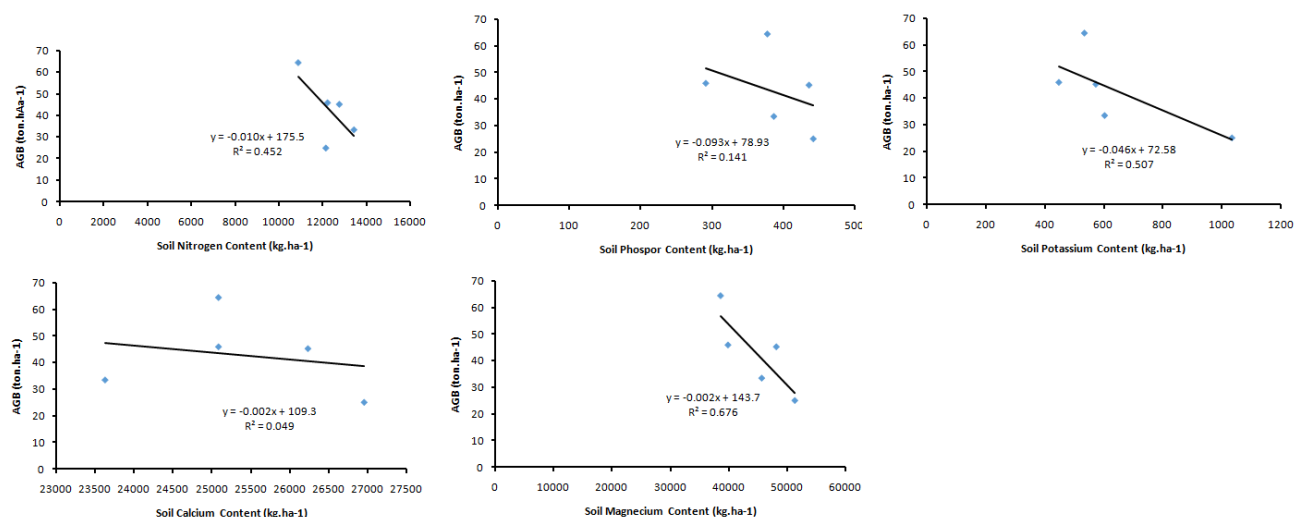
Figure 7. Corelation between soil nutrient content and aboveground biomass of *Macaranga gigantea* at five years old

Figure 8. The proportion of nutrients stored in the soil and nutrient accumulated in *Macaranga gigantea* plants at five years old.

Table 2. Soil nutrient contents in *Macaranga gigantea* plant at the age of five years

Fertilizer application	Soil depth	Soil nutrient content (kg.ha^{-1})				
		N	P	K	Ca	Mg
	30-60	5385.7	290.7	705.9	10159	24100
	0-60	12136.5	441.3	1034.2	26953	51292
P1	0-30	6561.9	191.8	280.8	8710	24068
	30-60	6182.6	243.7	293.1	17522	24043
	0-60	12744.5	435.4	573.9	26232	48111
P2	0-30	7667.8	140.9	373.1	15770	22234
	30-60	5737.6	245.6	230.6	7860	23369
	0-60	13405.4	386.5	603.7	23630	45603
P3	0-30	6867.9	96.9	239.4	11872	18774
	30-60	5342.8	195.0	209.5	13213	21026
	0-60	12210.7	291.8	448.8	25085	39800
P4	0-30	6045.9	153.8	281.5	12169	21444
	30-60	4842.8	223.6	253.7	9794	17076
	0-60	10888.7	377.4	535.2	21963	38520

Note: P0 = control without fertilizer, P1 = NPK fertilizer 40 g, P2 = NPK 80 g fertilizer, P3 = NPK fertilizer 120 g and P4 = NPK 160 g fertilizer.

The relative portion of N, P, Ca, and Mg nutrients stored in the soil was still very large, ranging from 89.76 to 99.93%, whereas that accumulating in *M. gigantea* stands was very small at 0.20% - 10.24%. It means that the absorbed nutrients of N, P, Ca, and Mg by *M. gigantea* were relatively small. On the other hand, the relative portion of accumulated K nutrients in the soil was quite small, ranging from 44.18 to 81.17%, while that in *M. gigantea* stands was large enough, ranging between 18.83 and 55.82%. It means that K was highly absorbed from the soil and was accumulated in *M. gigantea* plant tissue, followed by phosphorus, nitrogen, calcium, and magnesium (Figure 8).

Discussion

At the age of five years, the best growth of *M. gigantea* was found in P4 plot which was treated with NPK fertilizer at 160 g dosage (Figure 1). The same result was also found in aboveground biomass accumulation (Figure 3). In contrast to Susanto et al. (2017b) which found that at the age of one year the best growth and production of aboveground biomass were found in the application of NPK fertilizer with the dosage of 120 g. Nusbaum et al. (2005) reported that the application of fertilizer in degraded soil is able to increase dry weight, basal diameter, and height for all plant species at the age of 6 months. The increase in height and basal diameter in fertilized *M. gigantea* seedlings are four times higher than those in unfertilized plants.

The result also showed that the accumulation of nutrients N, P, K, Ca, and Mg in *M. gigantea* was the highest at the P4 treatment (NPK 160 g fertilizer). The highest N accumulation was found in the leaves, followed by branches of wood and bark. The highest P nutrient was stored in the branch followed by leaves, wood, and bark. On the other hand, K, Ca, and Mg nutrients were more accumulated in branches, wood, leaves, and bark. The highest absorbed nutrient by M. gigantea from the soil was K with 676.20 kg.ha-1, followed by N with 344.01 kg.ha-1, Ca with 114.57, Mg with 77.64 kg.ha-1 and P with 43.04 kg.ha-1.

The content of N, P, K, Ca and Mg in soil (0-60 cm) showed that plot P4 had the lowest nutrient content compared to Plots P0, P1, P2, and P3. Elements of K and P had a lower content than N, Ca and Mg nutrients. It means that *M. gigantea* plant more easily absorbs nutrients in the soil for its growth. This plant is a fast-growing pioneer species that requires high levels of light within forest gaps of secondary (Davies et al. 1998; Romell et al. 2008). Fast-growing tree species are generally considered to accumulate soil nutrients faster than slow-growing ones when multiple rotations are implemented (Cossalter and Pye-Smith 2003). Inagaki and Tange (2014) also reported that fast-growing Eucalyptus trees can accumulate more aboveground biomass than N$_2$-fixing and other non-N$_2$-fixing broadleaved trees while storing less aboveground N. Furthermore, some Acacia and Eucalyptus trees can produce more aboveground biomass than other non-N$_2$-

fixing broadleaved trees while using less Phosphorus. Montagnini (1998) reported that four years after planting, decrease in soil nutrients was apparent in pure plots of some of the fastest-growing species. On the other hand, some fast-growing tree species have strategies that allow them to grow on degraded soils. Montagnini (2000) reported that decreases in soil P, K and Ca were apparent in pure plots of the fastest-growing species with the largest accumulation of nutrients in above-ground biomass, such as *J. copaia* and *V. guatemalensis*, five years after planting.

In this study, the highest accumulation of nutrients was also found at P4 plot. Nitrogen was accumulated at 344.01 kg.ha-1, 121% higher than non-fertilized control plants which accumulated only 155.9 kg.ha-1. The accumulation of phosphorus in the biomass of *M. gigantea* at P4 plot was 43.04 kg.ha-1, twice higher than the phosphorus content in control plot with 20.9 kg.ha-1. Potassium accumulation was 676.20 kg.ha-1, three times higher than that at control plot (239.89 kg.ha-1). While for the calcium and magnesium nutrients, the accumulation of each nutrient in plant biomass was 114.57 kg.ha-1 and 77.64 kg.ha-1 at plot P4, twice higher compared to those at P0 control with 66.51 kg.ha-1 and 36.1 kg.ha-1. The addition of NPK fertilizer higher than 160 g significantly increased N, P, K, Ca and Mg content of *M. gigantea* plant biomass. This nutrient has important role in photosynthesis. The finding of this study is in accordance with Cossalter and Pye-Smith (2003), which states that fast-growing tree species are generally considered to accumulate soil nutrients faster than slow-growing ones.

Potassium is the most accumulated nutrient in *M. gigantea* biomass with 676.20 kg.ha^{-1}, consisting of 64% in stem and branch, and 36% in leaf and bark. On the other hand, the relative portion of K nutrients that were accumulated in *M. gigantea* stands was quite large, ranging between 18.83 and 55.82% (Figure 7) compared to other nutrients. This result shows that nutrient K is the most absorbed nutrient by *M. gigantea*. Hertemink (2001) reported that fast-growing species *Piper aduncum* also accumulated large amounts of biomass and nutrients, particularly K.

When *M. gigantea* plant is harvested at the age of five years with stems and branches taken out of the system, the greatest nutrient that will be reduced from the soil is potassium, followed by phosphorus, nitrogen, calcium, and magnesium. In the first cycle of harvesting *M. gigantea*, the soil will lose nutrients by 438 kg.ha-1 (64%), assuming that the leaves and barks were left on the site. Meckensen, (1999) and Meckensen et al. (2001) reported that nutrient content of fast-growing *Eucalyptus deglupta* in industrial plant forests in East Kalimantan (100 m^3 log and barks) was N with 44. 4 kg.ha-1, P with 2.3 kg.ha-1 and K with 125 kg.ha-1. Uri et al. (2003) found that the amount of nutrients accumulated by 1-year-old grey alder in producing one tonne of biomass at an N:P:K ratio of 100:9:43. The uptake of nutrient K by *M. gigantea* is more abundant than *Eucalyptus deglupta*. Montagnini (2000) reported that in monoculture plantations, *Vochysia guatemalensis* had the greatest accumulation of K and Ca. In *V. guatemalensis* plantation, stem harvest would remove

less than 30% of N for 50% of total above-ground tree Ca, K, Mg and P. Branches and foliage summed together contribute only 25 to 35% of total above-ground tree biomass, but they generally represent about 50% of above-ground tree nutrients. Mackensen and Foster (2000) reported that cost of fertilization is different across species. For example, fertilization costs for *Eucalyptus deglupta* are generally higher than *Acacia mangium*. Alriksson and Eriksson (1998) suggested that the choice of tree species harvest and stem-wood harvest is when they reach similar rates of stem-wood biomass production. On the other hand, Montagnini (2000) reported that continued sampling will be needed to assess the long term effects of plantation treatments on soil chemistry, especially near the end of the rotation

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