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Growth Performance, Biomass and Phytoextraction Efficiency of *Acacia mangium* and *Melaleuca cajuputi* in Remediating Heavy Metal Contaminated soil

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ABSTRACT

Heavy metals are very toxic and soil contaminated with sewage sludge urgently need remediation in order to avoid related health hazards. Phytoremediation is a low cost and reliable technique to remediate heavy metal contamination. However phytoremediation using timber species was rarely reported and its efficiency was questionable. A field study was conducted to examine the efficiency of two timber species namely *Acacia mangium* and *Melaleuca cajuputi* in phytoextraction of Zn, Cu and Cd from contaminated soil. Two hundred of *A. mangium* and *M. cajuputi* were planted on sewage sludge disposal site and the growth was recorded for 12 months before at the end total biomass of each species was determined. Results show in 12 months, about 72 and 4 t ha^{-1} of aboveground biomass can be produced by *A. mangium* and *M. cajuputi*, respectively. Both species show potential for phytoremediation, however *A. mangium* is more efficient compared to *M. cajuputi* where efficiency of *A. mangium* to remove Zn was 24.4, 6.2 for Cu and 9.5% for Cd. As for *M. cajuputi* the efficiency was 1.3, 0.3 and 0.14% for Zn, Cu and Cd, respectively. It is projected that *A. mangium* require 5, 17 and 20 years to remove 79.82 kg ha^{-1} of Zn, 46.94 kg ha^{-1} of Cu and 2.33 kg ha^{-1} of Cd, respectively.

Keywords: Phytoremediation, Extraction Efficiency, Heavy Metals, *Acacia mangium*, *Melaleuca cajuputi*

1. INTRODUCTION

Waste disposal is a greatest challenge for sustainable development. It was estimated that the Malaysian population will reach 30 million people in year 2020 and over 62% of it lives in urban areas (Khanif, 2010). According to Indah Water Konsortium (IWK), there are over 6 million cubic meter of sewage sludge generated in the Peninsular Malaysia which needs to be disposing safely (IWK, 2007). Common disposal methods for sewage sludge used worldwide are land disposal or landfills. However, land disposal of sewage sludge cause soils to be polluted especially with heavy metals. Soil contaminated with heavy metals urgently need to be remediated as heavy metals is indestructible and its ecotoxicity remained after introduction into the soil.

Conventional soil remediation methods could become unreliable due to complexity and dynamic nature of soils (Mirsal, 2008; Reddy *et al*., 1999; Reddy, 2008). Phytoremediation of soil contaminated with heavy metals is a low cost alternative and very reliable as it uses plants to extract and stores heavy metals in its

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tissues. However, phytoremediation depends on the plant species ability to absorb and transfer heavy metals to the harvestable parts for removal. Thus, this require a specific species especially hyperaccumulator species. Plant species suitable for phytoremediation must be tolerant to toxicity, fast growing and has high biomass (Abdu *et al*., 2011; Ahmadpour *et al*., 2010; Garbisu *et al*., 2002; Majid *et al*., 2011; 2012a; 2012b).

Majority of literatures use Bio-Concentration Factor (BCF) and Translocation Factor (TF) as a standard assessment for phytoremediation potential. Assessing species potential for phytoextraction by BCF or TF did not provide the information on the efficiency of the process (Majid *et al*., 2012c; Sundarajoo *et al*., 2013). Thus, the assessment lacks reliability as it only shows heavy metal accumulation capacity but not the amount that can be removed in any one growth cycle. In general, different species have different ability to accumulate heavy metals and the BCF values fluctuate according to treatment levels and site conditions.

Siegel (2008) stated that the most effective and efficient method to use in a remediation project on contaminated soils depends on various factors. Among these are characteristics of the soil, pollutant response to immobilization or mobilization procedures and assessment of the impact of the remediation method used on soil ecosystems. Relying on the BCF and TF values alone will therefore not be comprehensive and reliable in assessing the success of a phytoremediation project and efficiency of the selected species. Therefore, a field study was conducted to evaluate the efficiency of two tropical timber trees to extract heavy metals.

2. MATERIALS AND METHODS

2.1. Study Site and Data Collection

The study was conducted under field conditions in sewage disposal site in Juasseh, Negeri Sembilan, Peninsular Malaysia owned by Indah Water Konsortium, a national sewerage company system in Peninsular Malaysia. A total of 200 *M. cajuputi* and *A. mangium* in each plot (50×10 m) were planted in a row of about 2m from each other (2×2 m). The field study was conducted for 12 months. Growth was recorded bi-monthly by measuring the basal diameter of the stem and height. Growth analysis subjected to independent student *t*-test.

Soil samples were collected in five sub-plots of 3×3 m in each planting plot at depths of 20 cm. Leaves samples were also collected for heavy metal uptake analysis. Heavy metals in the plants and soils were extracted by wet digestion method with aqua-regia solution. Recovery tests were conducted to ensure reliability of extraction process by mean of Standard Reference Material (SRM) certified materials for plant sample (material code 1573A; tomato leaves) and soil (material code HISS-1; marine sediment) obtained from United States National Institute of Standard and Technology (NIST). The SRM was treated the same way as all samples were treated. In this study, 90% recovery was obtained and maintained.

2.2. Plant Biomass Determination

At the end of study period of 12 months, four trees of each species were selected and subjected to destructive sampling based on the average measurement of stem diameter and height. The felled trees were then divided into leaves and stems and weighed for the total fresh biomass. About 1 kg of leaves, stems and roots were taken to the laboratory for drying as representative samples. For more accurate estimation of biomass of large trees such as *A. mangium*, Smalian's formula was used to calculate the total volume of the *A. mangium* stem. The stems with large diameter between 5cm to 10cm were cut into shorter manageable length of about 50cm, weighed and tagged accordingly. Then sample discs were sawed with thickness of 5 cm on both ends of the stems and taken to the laboratory for drying. The stems of less than 5 cm (or twigs) are weighed together and samples weighing 1kg were taken to the laboratory for drying.

2.3. Phytoextraction Efficiency

Zhao *et al*. (2003) suggested that phytoextraction efficiency can be estimated by calculating percent of metals or nutrients in the harvestable biomass against the concentration of the metals in soil mass where the species was planted as shown in the equation below:

$$\text{Phytoextraction Efficiency } (\%) = \frac{C_{plant} \times M_{plant}}{C_{soil} \times M_{rooted\ zone}} \times 100$$

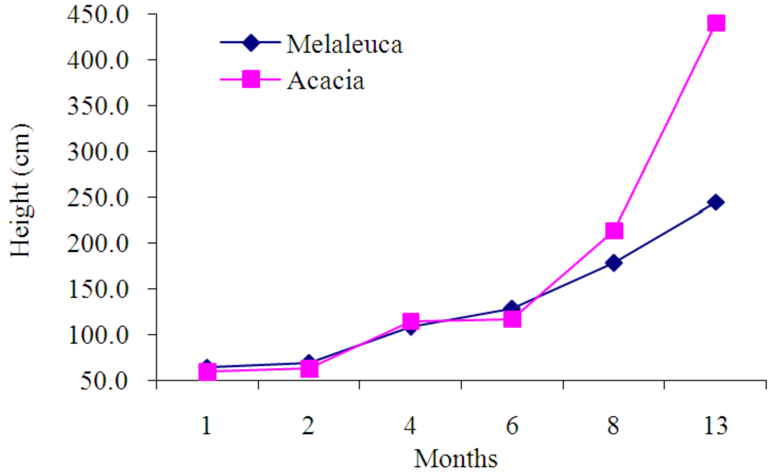
Where:

C_{plant} = Concentration in harvestable plant tissues
M_{plant} = Biomass of harvestable part of the plant species
C_{soil} = Concentration in the soil and
$M_{rooted\ zone}$ = Soil mass penetrated by the roots

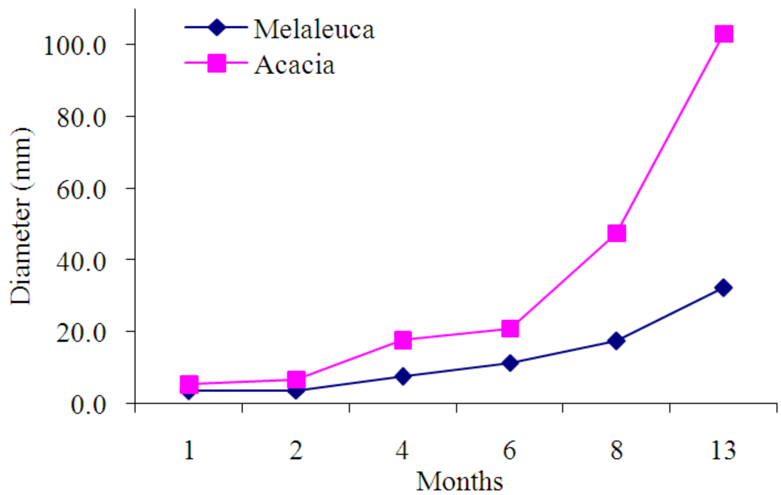
3. RESULTS AND DISCUSSION

3.1. Characteristics of Selected Soil Physico-Chemical Properties

Table 1 shows the soil condition of the study site at the beginning of the study. Soil pH was very acidic and CEC was high.



(a)



(b)

Fig. 1. *A. mangium* and *M. cajuputi* (a) height and (b) basal diameter in the field experiment

Table 1. Soil condition in the study plot

pH	3.21
CEC (cmol/kg)	53.40
Soil density (g/cm^3)	1.00
Carbon (%)	3.70
Zn (mg/kg)	38.22
Cu (mg/kg)	21.15
Cd (mg/kg)	1.04

The concentration of heavy metals namely Zn, Cu and Cd were 38.22, 21.15 and 1.04 mg kg^{-1}, respectively. The concentrations were moderately contaminated compared to the normal concentrations in uncontaminated agricultural soil in Malaysia as reported by Zarcinas *et al*. (2004).

3.2. Growth Performance of *Acacia mangium* and *Melaleuca cajuputi*

Figure 1 shows the growth performance trend of *A. mangium* and *M. cajuputi* in the field experiment. Average initial height for both species was about 50 cm. The growth of both species was almost equal in the subsequent months at about 60 cm in the second month, 100 cm in the 4th month and 130 cm in the 6th month. Only after the 8th month there was a significant difference ($p \leq 0.05$) in height between the two species where height of *A. mangium* reached an average of about 210 cm but *M. cajuputi* was only about 170 cm. The height of *A. mangium* has subsequently increased reaching up to 450 cm at the end of the experimental period. However, the average height of *M. cajuputi* at the end of the experimental period was only about 240 cm.

Similarly, basal diameter of the two species shows that in the first 3 months the increase in basal diameter was not significant between the two species ($p \leq 0.05$). The initial basal diameter for both species was about 10 mm, increased slightly to about of 15 mm in the subsequent month. Only after six months, the basal diameter of the two species was significantly different ($p \leq 0.05$). The basal diameter of *A. mangium* has reached about 40 mm in the 8th month and 100 mm at the end of the experimental period. On the other hand, basal diameter of *M. cajuputi* was below 20 mm until the 8th month and increased to 30 mm at the end of the experimental period.

Slow growth in the first three to four months after planting was considered as an adaptation period for both species. The soil pH in the study plot was very acidic (**Table 1**) and might have cause stunted growth. Plant growth is subjected to soil pH (Abdu *et al*., 2008; Akbar *et al*., 2010; Justin *et al*., 2011; Wang *et al*., 2006) and low pH encourages heavy metal release that is available for uptake and cause toxicity to the plant (Parkpain *et al*., 2000). However, both species showed tolerance to acidic soil and high heavy metal concentration as the growth improved after the adaptation period.

However, *M. cajuputi* not able to withstand dry conditions in the study plot hence causing high mortality. White *et al*. (1997) stated that this species has high evapotranspiration rate and thrives in wet conditions. On the other hand, Maiti (2007) stated that *A. mangium* is a species that tolerates dry conditions with low soil bulk density. The potential of the two species for phytoextraction is promising but soil moisture in this case seems to be the limiting factor for *M. cajuputi*.

3.3. Biomass of *Acacia mangium* and *Melaleuca cajuputi*

Table 2 shows the growth measurement of the two species in the field experiment. The growth of *A. mangium* was better compared to *M.cajuputi* during the 12 month experimental period. Average height of *A.mangium* at the end of the study period was 4.4 m, stem basal diameter was 10.32 cm and the crown covered an area of about 11.56 m^2. The roots of *A. mangium* reached 1.33 m in depth. The weight of *A. mangium* shoots was about 28.71 kg and the roots were 7.71 kg. As for *M. cajuputi*, the average height was 2.5 m, stem basal diameter was 3.3 cm and crown area of about 0.25 m^2 with root depth of only 0.9 m. The shoot biomass of *M. cajuputi* was 1.59 kg and the roots were 0.4 kg.

The results evidently show that *A. mangium* grows faster than *M. cajuputi* and this characteristic is desired for phytoremediator (Siegel, 2008; Padmavathiamma and Li, 2007). The shoot biomass of *A. mangium* is about 18 times higher than *M. cajuputi*. Hoshizaki *et al*. (2004) and Benomar *et al*. (2012) stated that stem biomass is influenced by the density of trees planted in an area. In the case of the present study, high density planting designed for the experiment was expected to produce large biomass hence more effective phytoextraction capability. In addition, *A. mangium* has deep rooting system and large crown cover that could minimize water percolation which helps control heavy metal vertical migration.

3.4. Assessment of Extraction Efficiency by *Acacia mangium* and *Melaleuca cajuputi*

Table 3 shows the amounts of Zn, Cu and Cd that can be accumulated in a single plant of both species based on the biomass and accumulation level in 12 months. The average concentrations of Zn, Cu and Cd in *A. mangium* aboveground parts were about 200 mg kg^{-1}, 40 mg kg^{-1} and 2.0 mg kg^{-1}, respectively. As for *M. cajuputi* the concentrations for Zn, Cu and Cd in the shoots were 160, 30 and 1.0 mg kg^{-1}, respectively. Thus, the aboveground biomass of a single *A. mangium* tree in 12 months is projected to accumulate 5.74 g of Zn, 1.15 g of Cu and 0.06 g of Cd. In the case of *M. cajuputi*, the amounts of Zn, Cu and Cd projected to be accumulated in a single plant during the experimental period were 0.25, 0.05 and 0.002 g, respectively.

Table 2. Average measurements of growth and biomass in the field after 12 months

Species	Ht (m)	BD (cm)	CA (m^2)	RD (m)	Biomass (kg) Shoot	Biomass (kg) Root
A. mangium	4.4	10.32	11.56	1.33	28.71	7.71
M. cajuputi	2.5	3.30	0.250	0.90	1.590	0.40

Note: Ht = height; BD = basal diameter (stem); CA = crown area; RD = root depth

Table 3. Concentration of Zn, Cu and Cd in the field experiment and total accumulation in individual plant

	A. mangium			*M. cajuputi*		
	Zn	Cu	Cd	Zn	Cu	Cd
Concentration (mg/kg)	200.00	40.00	2.00	160.00	30.0	1.00
Total in individual plant (g)	5.740	1.15	0.06	0.30	0.05	0.002

These amounts were far from 1% of the total harvestable biomass thus clearly indicating that both species were not hyperaccumulator. Baker and Brooks (1989) studied several families of higher plants such as Asteraceae and Brassicaceae and found that a hyperaccumulator species should at least accumulate heavy metals at about 1% of the total biomass produced.

As for the efficiency of phytoextraction, it was calculated on kg/ha basis to have a realistic soil mass involved. Hence, the total biomass of both species was multiplied by 2,500 plants in a hectare or 10, 000 m^2 (4 m^2 per individual plant or 2×2 m planting distance). The phytoextraction efficiency of the two species is shown in **Table 4**.

A. mangium has the highest Zn extraction efficiency percentage at 24.4%, followed by Cd and Cu for, each with 9.53 and 6.25% respectively. In the case of *M. cajuputi*, the highest phytoextraction efficiency was also for Zn at 1.32%, followed by Cu (0.33%) and Cd (0.14%). This apparently shows that *A. mangium* is far more efficient compared to *M. cajuputi* especially for Zn. Over 20% of Zn can be removed from the soil within a year with the biomass produced. Adler *et al*. (2008) who conducted phytoremediation studies on several woody and herbaceous perennials species found that trees need longer time to establish (to produce large biomass) but have higher nutrient uptake and use efficiency.

3.5. Phytoremediation Projection Period on Soil-Sewage Sludge Contamination

The time required for phytoremediation can be projected using a simple calculation from biomass generated in the current experiment. However, this estimation is not accurate as there are limitations such as the effect of climate and growth. This estimation only attempted to illustrate the efficiency of the two species in the field site.

The estimation of time needed to reclaim the contaminated soil was based on the assumption that biomass generated from both species and the accumulation levels in the shoots (**Table 2**) were constant. Total annual biomass of shoot or aboveground parts of *A. mangium* and *M. cajuputi* was estimated at about 72.0 tonnes ha^{-1} and 4.0 tonnes ha^{-1}, respectively. The targeted concentration for removal was set using the lowest level of uncontaminated soil in Malaysia as reported by Zarcinas *et al*. (2004) where Zn is 2.9 mg kg^{-1}, Cu and Cd were 0.37 mg kg^{-1} and 0.01 mg kg^{-1}, respectively. In this estimate, the amount for removal was the difference of concentration between targeted level and the initial topsoil concentration as in **Table 1**.

Table 4. Phytoextraction efficiency (%) in the field experiment

	Zn	Cu	Cd
A. mangium	24.43	6.25	9.53
M. cajuputi	1.320	0.33	0.14

Table 5. Estimated time (years) required to remove heavy metals by extracting the generated biomass in field experiment

	Amount to be removed, A (kg/ha)	Annual removal by biomass, B (kg/ha)		Estimated time, A/B (year)	
		A. Mangium	*M. Cajuputi*	*A. Mangium*	*M. Cajuputi*
Zn	79.82	16.49	12.91	4.84	6.18
Cu	46.94	2.80	2.65	16.79	17.69
Cd	2.33	0.12	0.06	19.68	38.20

Table 5 shows that *A. mangium* requires about 5 years to remove Zn from the soil to a safe level, about 17 years and 20 years to remove Cu and Cd, respectively. However, for *M. cajuputi*, the time estimated to extract the metals were slightly longer, about 6 years for Zn, 18 years for Cu and 38 years for Cd. However, if good silvicultural practices were applied such as application of fertilizers and other interventions, the biomass could have been higher thus could possibly reduce the time for heavy metal removal.

In this study, *M. cajuputi* growth was relatively slow possibly due to water stress as this species is known to flourish in swampy areas. In the wild the growth is usually very much faster (Rayamajhi *et al*., 2006; Finlayson *et al*., 1993). *M. cajuputi* forest is a very productive forest and in Florida this tree species is considered as an invasive species (Lopez-Zamora *et al*., 2004). However, there is lack of published work on the physiological stress of this species.

4. CONCLUSION

If the aboveground biomass of *A. mangium* and *M. cajuputi* estimated at about 72.0 tonnes ha^{-1} and 4.0 tonnes ha^{-1}, respectively is maintained annually, about 5 years needed by *A. mangium* to remove 79.82 kg ha^{-1} of Zn, about 17 years to remove 46.94 kg ha^{-1} of Cu and 20 years to remove 2.33 kg ha^{-1} of Cd. However, *M. cajuputi* need slightly longer period to remove the same amount of Zn and Cu, projected about 6 and 18 years but 38 years to remove same amount of Cd. Although both species show potential for phytoremediation but *A. mangium* is evidently more efficient.

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