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VIABILITY OF PHYOEXTRACTION TO REMEDIATE HEAVY METAL CONTAMINATED SOIL USING TIMBER SPECIES

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Abstract: Phytoremediation is a low cost soil remediation technique which had made no wide-reaching. Within the instant, phytoremediation technique using timber species have been rarely reported. This study is intended to examine a timber species i.e. *Acacia mangium* ability to extract Zn, Cu and Cd from contaminated soil. A field experiment was conducted on a sewage sludge disposal site for a duration of 12 months. Results had shown that *A. mangium* aboveground biomass accumulates 200mg/kg of Zn, 40mg/kg of Cu and 2.0mg/kg of Cd at the end of experiment. It is estimated that 339t/ha of aboveground biomass would be required in order to remove 79.8kg/ha of Zn, 1,173 t/ha biomass for 46.9kg/ha Cu and 1,165t/ha biomass for 2.33kg/ha for Cd to pass an acceptable safe level, and this exercise can be achieved within 3 years. In a 10-year period, it is estimated that 25,300m^3 of timber would cultivated thus offers a rewarding substantial income of approximately USD 1.6 million. This evident postulate that phytoremediation is a commercially viable remediation approach and ought to be widely applied as a sustainable answer for contaminated soil remediation.

KEYWORDS: *Acacia mangium,* phytoremediation, economic evaluation, sewage sludge, soil remediation

Introduction

The ever rapid world population growth had forced pressure on the scarce earth-soil resources in sequence to constantly provide food (Khanif, 2010). Soil contamination is an impeding global enigma, as the continuing degradation has resulted in numerous negative consequences such as; poor air and water quality, increase spread of diseases and biodiversity losses (Zhao *et al.,* 2006). The scale of soil contamination has not been properly determined. In Malaysia, Department of Agriculture (2006) reported that there are over 2 million hectares of degraded soil with over 200,000ha of mined land that are badly polluted and urgently need remediation. Slow rate of soil clean-up is due to societal complacency or lacking in government policy (Gillespie & Philp, 2013) and in the Malaysian context, most soil remediation is conducted on voluntary basis (Yang *et al.,* 2006).

Phytoremediation is a process of remediating contaminated soils or ground water using plants as the cleaning instrument (Padmathiavamma & Li, 2007). Conventional soil remediation methods usually cause soil disturbance, rendering it incapable to support plant growth. Phytoremediation offers safe and efficient soil remediation method as it uses plants, of which subsequently stimulates soil organisms thus restores soil functions. After decades of intensified research and development processes, phytoremediation is yet to be widely applied (Monpetit & Lachapelle, 2017). In Malaysia, this technique is almost non-existent, the practice is only limited to laboratory scale in various research institutions (Yang *et al.,* 2006).

Therefore this study was conducted to evaluate the efficiency and feasibility of phytoremediation technique using a common timber species found in forest plantation in

Malaysia i.e. *Acacia mangium,* to remove soil metal contamination in a sewage sludge disposal site. This examination was aimed to determine the amount of *A. mangium* aboveground biomass that is required to extract heavy metals, namely, Zn, Cu and Cd from sewage sludge contaminated soil and furthermore to estimate the economic value of a phytoremediation project using the species.

Material and Method

Field Experimental Design

A field experiment was conducted in an area of approximately 0.5 ha sewage disposal site owned by the National Sewerage Company, Indah Water Konsoritum (IWK) Sendirian Berhad, located in Juaseh, Negeri Sembilan (2o48'49.64"N, 102o18'39.98"E). The study plot has 12 sewage disposal trenches measured approximately a meter in depth with 10m in length and 2m wide. A total of 220 *A. mangium* saplings were planted on ridges alongside the trenches with a gap of 2m from each other (Figure 1). Minimum care was treated to the *A. mangium* saplings during the study period, where weeding activity was conducted only in the first three months to ensure the saplings survival and no fertilizer applications were given throughout the period.

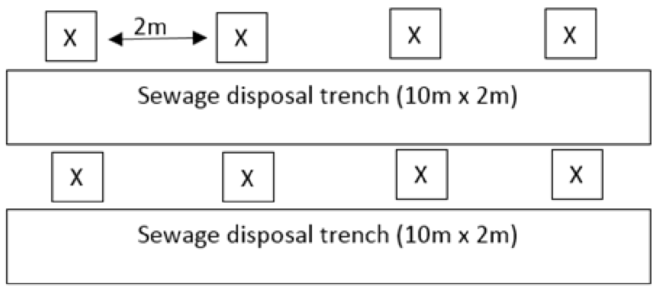

Figure 1: Planting arrangement in the field experiment

Soils samples were collected at depths of 0-20cm alongside the ridges in between the saplings, at before and after the experiment phases for further analysis. Growth of *A. mangium* was observed by measuring the basal diameter of stems and height, which were taken monthly for a duration of 12 months. Above ground plant samples were also collected for examinations of heavy metal uptake analysis at the end of the study period.

Laboratory Analysis

Dried plant and soil samples were analysed for their total heavy metal concentrations, namely; Zn, Cu and Cd, the samples were treated with wet digestion procedures. One gram of each sample was placed in a 250mL digestion tube with an addition of 10mL of concentrated nitric acid. The samples were heated for 45 min at 90°C, then the temperature were further increased to 150°C at which the samples were boiled for at least 8 hours until a clear solution obtained. After cooling, the solution was filtered with medium grade (fast) filter papers. It was then diluted to 100mL in a volumetric flask by adding distilled water. Heavy metal concentrations were determined by using Atomic Absorption Spectrophotometer (Zheng-Yei, 2004). Recovery test was conducted with assessment to the standard reference material certified by United States National Institute of Standard and Technology and was examined using tomato leaves (material code 1573A) and marine sediment (material code HISS-1). In this study, recovery was recorded between 93 to 105%.

Biomass Estimation for Heavy Metal Extraction

In consideration to avoid widespread perception of less effective phytoremediation due to the impairing difficulties in predicting the end point of the remedial process, this study employed a target level that is common in most of agricultural soil in Malaysia as reported by Zarcinas *et al.* (2004) (Soil mean concentration for Zn = 2.9mg/kg; Cu = 0.37mg/kg and Cd = 0.01mg/kg respectively). The amount of biomass of *A. mangium* that is needed to remove the metals was estimated by using the allometric equation developed by Heriansyah *et al.* (2007) for *A. mangium* plantation that has over 80% accuracy. Statistical analyses were performed by Assistat version 7.0 and MS Excell software.

$$W_i = a(D^2H)^b$$

where: W_i = biomass of component *i* (aboveground in kg)
a and b = constants
D = basal diameter
H = height

Results and Discussions

Heavy Metal Extraction Efficiency

At the end of experiment period, the total concentrations of Zn, Cu and Cd accumulated in the leaves, stems and twigs of *A. mangium* were found to be exceedingly higher than the soil concentrations, as shown in the Table 1, thus demonstrating that the species has the ability to accumulate a fairly high amount of heavy metals in the above ground biomass. Concentration of Zn in *A. mangium* above ground biomass was found 7 times higher than in the soil. As for Cu and Cd accumulation in the *A. mangium* recorded 2 times higher than soil concentrations. It was observed that the plants growth does not indicate any toxicity symptoms and has grown well, which suggests that *A. mangium* has shown capable tolerance to heavy metals and have the capability for heavy metal extractions from the soil. Thus continuous bioremediation on heavy metal polluted soil is possible using the same plant.

Table 1: Mean concentration of Zn, Cu and Cd in the soil and accumulated in the above ground biomass.

Elements	Concentration in aboveground biomass (mg/kg)	Concentrations in the field soil (mg/kg)
Zn	200.0	26.04
Cu	40.0	19.69
Cd	2.0	1.11

It is impossible to eliminate heavy metals from the soils which consequently give the perception of inefficiency. Remediation of contaminated soil should reduce the concentration of the metals to acceptable or safe level (Wiséen & Wester-Herber, 2007). Thus, Table 2 shows the amounts of heavy metal that needed to be removed from the study field soil sample to a safe level as reported by Zarcinas et al. (2004). Therefore, according to the concentration of heavy metals in biomass as shown in Table 1, it was estimated that the aboveground biomass of *A. mangium* needed to be removed in order to achieve the targeted concentration level was about 340 t/ha for Zn and over 1,170 t/ha for Cu and Cd.

Table 2: Biomass of *A. mangium* required to remove the heavy metals from study site

Elements	Study site soil concentration (kg/ha)	Amount to be removed from soil (kg/ha)	Biomass required for removal (t/ha)
Zn	382.2	79.82	339.1
Cu	211.5	46.94	1,173.5
Cd	10.4	2.33	1,165.0

The height and diameter of *A. mangium* used to estimate the aboveground biomass was obtained through the log linear regression analysis (Figure 2) of the 12 month field experiment growth and was projected in extrapolation to a full 10-years growth cycle; as taking into account that after 10 years length, biomass production will begin to decline and stem diameter growth will achieve optimum size qualified for commercial logs.

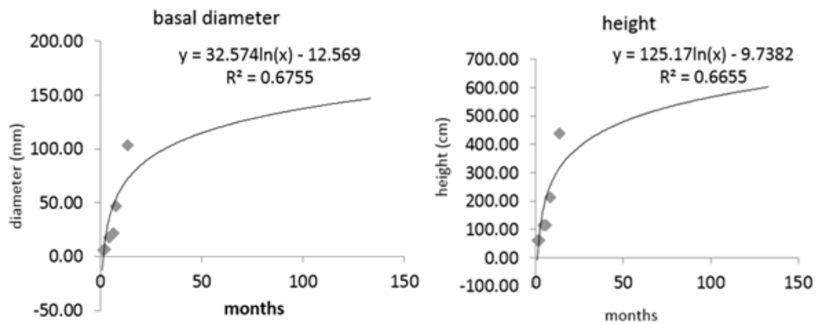

Figure 2: Estimated Height and basal diameter of *A. mangium* in the field experiment using simple linear regression analyses.

Growth beyond 10 years may not be feasible and cost attractive for phytoremediation to be applied as the maintenance expenses and other unspecified external influences may perhaps significantly affecting the soil rehabilitation process. Table 3 shows the constant values used in the estimation of *A. mangium* plantation without any specific stand age.

Table 3: Allometric equation constants for estimating the biomass of *A. mangium.*

Tree biomass	-log a	b
Stem	1.7143	0.9934
Branch	2.4877	1.0087
Leaf	1.6106	0.6173

Therefore, assuming that the accumulation of heavy metals in the above ground biomass is to be constant during the study period and by analysing the allometric equation proposed by Heriansyah *et al.* (2007) in accordance to the growth data gathered from the field, the estimated duration for *A. mangium* biomass needed (Table 3) to remove Zn, Cu and Cd would be achieved after 2 years length, wherein 1,300t/ha is estimated to be generated compared to 1,117 t/ha that was required (Table 4). Despite the fact that most species of trees including *A. mangium* usually store heavy metals in the roots (Ang *et al.,* 2010), the thinning process in *A. mangium* plantation enhances carbon deposition in the soil (Vijayanathan *et al.,* 2011) which in turn may cause heavy metals to be retained in the soil.

Table 4: Estimation of annual biomass for *A. mangium* plantation using allometric equation by Heriansyah *et al.* (2007).

Application period of phytoremediation	Study site soil concentration (kg/ha)	Amount to be removed from soil (kg/ha)	Biomass required for removal (t/ha)
1	6.84	3.01	619.15
2	9.09	3.88	1,387.57
3	10.42	4.39	2,044.32
4	11.35	4.75	2,618.08
5	12.08	5.02	3,130.41
6	12.67	5.25	3,595.43
7	13.18	5.45	4,022.73
8	13.61	5.61	4,419.15
9	13.99	5.76	4,789.70
10	14.34	5.89	5,138.22
		Cumulative biomass	31,764.77

However, the aboveground biomass generated is at a very high rate and thus the total amount needed to remove the metals to safe level may be achieved relatively fast. Moreover, Karami & Shamsuddin (2010) has shown that the efficiency of phytoremediation is able to be enhanced (or at least remain constant such as in this case) and it is achievable by maintaining low pH soil or vide the use of chelating agent to maintain the available pool of heavy metal uptake. Therefore, it is reasonable to estimate that the metal concentrations could be reduced to the targeted safe level concentration in the third year where the biomass generation is doubled (Table 4) that of the estimated minimum required amount (Table 2).

Phytoremediation Economic Evaluation

It is important to ensure that phytoremediation be commercialised in the future as the application cost of this technique is low and the length of remediation period is relatively short. The commercial success of phytoremediation approach is dependents upon the generation of its valuable biomass produce. Perhaps, should a multi-purpose species is benefited, the biomass produces an even more potential income (Conessa *et al.,* 2012). This study has demonstrated that with minimum interventions, the contaminated site is safe for agricultural use after 3 years. According to Krisnawati *et al.* (2011) the biomass production of *A. mangium* will decline and stem diameter will achieve the optimum size for commercial logs after 10 years. Thus, this study reported an estimate of 10 years phytoremediation cycle that will produce quality timber as the shortest time wherein to ensure phytoremediation process become economically viable.

Timber is traded in stem volume and the current price for *A. mangium* timber fluctuates according to the market supply and demand. Currently, there is no official standard of pricing for *A. mangium* log in Malaysia. According to the United Nation Food and Agriculture Organization, FAO (2002) which stated that log prices had always differ according to timber species, year of harvest and, purpose use or type of product. Online search of various commerce webpages shows that the price of *A. mangium* varies ranging from USD 63.77/m^3 to USD 264.44/m^3. However, in this study, the price is set at USD 63.77/m^3 (lowest range) for a fair estimation and without overprice. With over 31,000t/ha of biomass generated after 10 years (Table 4), at about 80% from or 25,300m^3 of logs can be harvested (Table 5) and hence it is estimated that over USD 1.6 million shall be earned from phytoremediation application for each hectare of land. This shows that *A. mangium* has high potential to remediate metal contaminated soils and it is a feasible technique for soil remediation.

Table 5: Estimated timber volume of the *A. mangium* in phytoremediation project after 10 years.

	Produced (m^3)	**Unit price (USD/ m^3)**	**Estimated earnings (USD/ha)**
Stem volume	25,300	63.77	1,611,673.25

Conclusions

Removing heavy metals using a common avail timber species, *A. mangium* to a safe level, requires over 1,173t/ha of above ground biomass, and it is evaluated that the study site is considered safe for agricultural use within 3 years, with biomass generated estimated to be over 2,000t/ha within the period. In addition, should *A. mangium* left to grow until the next 10-year period, it is estimated that over 31,000t/ha of biomass will be generated with a possible harvest of 25,300m^3 of timber, hence, the revenue that is estimated to be earned is approximately USD 1.6 million. This study has demonstrated that phytoremediation technique to remove heavy metals from contaminated soil is feasible and sustainable. Thus *A. mangium* forest plantation is found to be a sustainable approach to remediate contaminated soil due to its low cost and relatively fast remediation period.

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