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Phytoremediation of heavy metals using *acacia mangium* in rahman hydraulic tin (RHT) tailings, Klian Intan, Malaysia

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Introduction

Malaysia was once a renowned in the tin mining sector and formed the backbone of the country's economy. Due to over exploitation to feed the growing steel industry, most of the resources have been exhausted and these areas are left abandoned. Some suggest planting agricultural crops on these lands but a major concern is the presence of large amounts of heavy metals that are potentially toxic such as cadmium (Cd), lead (Pb) and arsenic (As).[1] which are detrimental to human health when occurs beyond permissible amounts.[2] A more feasible option would be to establish forest stands including *Acacia mangium* mainly because of its notable track record as a Phytoremediation. The *Acacias* have the potential to rehabilitate the soil through absorption and storage of heavy metals in its leaves, shoots and roots.[3] and even used in treating sewage sludge soil to absorb large amounts of zinc (Zn), Pb, copper (Cu), Cd and chromium (Cr).[4] Phytoremediation is a process that utilizes plants to filter and remove contaminants through biological, physical and chemical activities initiated by the plant. Phytoremediators act as filters by first absorbing contaminants, degrading them and stabilizing the concentrations of contaminants in soil through plant uptake. This study was initiated to determine the amount of heavy metal uptake and translocation to harvestable parts as well as to quantify the concentration of heavy metal before and after planting *Acacias*.

Methodology

The study was conducted in Rahman Hydraulic Tin Sdn. Bhd. in the vicinity of Klian Intan, Perak, Malaysia, situated between latitudes 05°25'N and longitudes 101°8' E. This area was previously mined for tin since the 1920s. The adjacent areas are surrounded by ex-tin mining ponds with large amount of tin wastes which consists of mud, liquid, sand, silt and sand. The planting area was limed and added with top soil as part of the rehabilitation program. Approximately 4 ha were planted with *Acacia mangium* on December 2012 spaced at 2 m x 2m and 4m x 4m. In December 2016, three *Acacia* trees were selected for sampling with diameter at breast height (DBH) and total height being taken prior to felling. The logs were cut into different lengths namely 0.3m, 1.3m and 7.3m (Figure 1). The fresh weights of the leaves were weighed whole and 3 replicates were taken from each tree amounting to 200 g. The roots from each tree was excavated and sorted into big roots and small roots for biomass determination. The fresh weights of roots were weighed whole and three replications amounting to 1 kg were taken as samples. Tree branches were also measured and determined in a similar manner. Soil samples were collected in triplicates at a depth of 0–65cm, 65–80cm and 80–100cm. Soil samples and tree samples were also taken from Bukit Hari, FRIM Selangor which served as the control. Leaves, roots and shoots from both sites were retrieved and taken to the laboratory for further analysis. Soil samples were air dried and ground in a Wiley mill and then sieved using a 1mm and 2mm sieve. The tissue samples were oven dried at 70°C and ground with Wiley mill (1mm sieved). The soil samples were digested using *Aqua-regia* method[5] for extraction of heavy metals. Heavy metals in plant tissues were extracted using nitric acid and hydrogen peroxide by the microwave digestion method. The concentrations of heavy metals in the plant and soil extracts were then analyzed using the Varian 725 Inductive Couple Plasma Optical Emission Spectrometer (ICP-OES).

Figure 1 Sampling process, destructive sampling of trees, cross sectional disc samples and lateral roots of *A. mangium* roots from RHT plot and weighing of roots for biomass determination.

Results and discussion

The Aluminium (Al) concentration recorded in soils under tin tailings ranged from 0.86–6.14% whereby concentrations decrease with depth and are much lower than values obtained for the control (Bukit Hari) which may implicate that *Acacias* were successful in absorbing Al (Table 1). Based on past reports, the pH of soil in tin tailings were very acidic and ranged from 2.4–3.3.[6] When pH is less than 5.5, Al tends to accumulate resulting in a condition known as Al toxicity, restricting root growth.[7] The phenomena of root restriction were seen in terms of biomass whereby the RHT plot recorded a much lower biomass compared with the control plot. The low levels of Al recorded in the leaves of RHT could be also due to Al ion translocated very slowly to upper parts of plants (Table 2).[8] However, Al concentration in wood discs were quite notable in the range of 24–53 mg/kg which indicate that woody components were more efficient in storing Al compared to leaves and roots (Table 2). In iron (Fe), the concentration in soil ranged from 1–6% which is slightly higher than observed in the control while the concentrations in leaves and roots were 200 and 1,500–2,800 mg/kg, respectively (Table 1) (Table 2). High concentrations of Fe at the Rhizosphere region compared with the leaves are due to the creation of iron plaque (Fe2O3), hindering excessive amount of Fe entering the plant tissue.[9] Thus, relatively lower levels of Fe were observed in leaves (Table 2) and wood disc samples (Table 3). Phytoremediation methods, particularly phytoextraction, have been used on a variety of metal contaminants including Fe[10] and works on the basis of transporting and accumulating large quantities of metals from the soil into harvestable parts of roots and aboveground shoot. According to the results, Cu in soil ranged from 50−79 mg/kg which was more than 70 times higher than the control (Table 1). Copper values were low in tissue, wood and roots thus confirming that A.mangium was able to absorb Cu in lesser quantities only. Similarly, the values for Pb were 30−330 mg/kg in soil and increased with depths and were higher than control.

Table 1 Soil analysis results from Bukit Hari (CON) and RHT (TRT) area

Soil depth (c)	**Heavy metal concentrations**															
	Total Al		**Total Fe**		**Total As**		**Total Pb**		**Total Zn**		**Total Ni**		**Total Hg**		**Total Cu**	
	(%)				(mg/kg)											
	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT
0-65	9.51	6.14	2.22	5.12	Trace	0.02	63.27	30.38	28.43	43.14	6.11	34.14	ND	ND	1.45	50.35
65-80	9.93	1.64	2.81	2.11	Trace	0.12	115.24	211.86	29.6	ND	7.5	21.14	ND	ND	0.9	79.41
80-100	9.96	0.86	2.98	1.26	trace	0.19	147.62	330.24	31.97	ND	8.27	21.89	ND	ND	0.53	79.1

Table 2 Tissue analysis results from Bukit Hari (CON) and RHT (TRT) area

Tissue samples	**Heavy metal concentrations**															
	Fe		**Al**		**As**		**Cu**		**Hg**		**Ni**		**Pb**		**Zn**	
(mg/kg)																
	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT
Leaf	197.9	200	120.62	0.02	ND	12.76	9.09	9.75	ND	0.13	1.55	1.47	ND	0.51	17.1	16.83
114.13	1500	265.34	0.26	0.8	11.04	1.88	3.16	ND	0.04	1.03	2.58	3.76	1.78	1.13	4.3	
Small roots	ND	2800	ND	0.48	ND	18.22	ND	4.86	ND	0.05	ND	5.12	ND	4.88	ND	6.34

Table 3 Wood disc cross sections results from Bukit Hari (CON) and RHT (TRT) area

Wood disc (m)	**Heavy metal concentrations**															
	Fe (mg/kg)		**Al**		**As**		**Cu**		**Hg**		**Ni**		**Pb**		**Zn**	
	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT	CON	TRT
0.3	83.04	76.64	71.23	52.42	4.02	ND	1.04	1.08	ND	ND	1.25	0.69	ND	0.45	3.13	ND
1.3	83.09	58.65	36.1	24.53	ND	1.18	0.75	1.19	ND	ND	0.63	0.91	ND	2.28	7.79	3.52
7.3	22.24	132.79	26.46	53.14	1.1	1.22	0.2	1.88	ND	ND	0.59	0.77	1.22	0.73	2.4	28.94

ND, Not Detected; CON, Control; TRT, Treatment

Values for tissue samples overall were less than 5 mg/kg as most of the Pb were translocated to the roots compared with the discs and leave samples. It was seen here that A. mangium was not able to sequester Pb in high quantities thus classified as a low phytoremediator. We believe that Pb was less mobile in soil as it may have bind strongly with oxides of Fe, manganese (Mn) and Al.[11] The concentration of zinc (Zn) in the soil was 43 mg/kg in the 0−65 cm profile. This was not detrimental to trees. Both tissues samples of discs and roots showed values less than 10 mg/kg. Leaves were on the higher side at 17 mg/kg comparable to control (Table 2) but still within a normal range for tissue samples. Zinc was translocated to leaves compared with other parts of the trees which show a good example of moderate Phytoremediation of A. mangium trees. Nickel (Ni) values were 20−35 mg/kg in soil (permissible level) and less than 1.5 mg/kg in discs and leaves similar to control (Table 1) (Table 2). Roots showed 5ppm had the highest amount among other tissue samples. Mercury (Hg) levels were somewhat absent in soil and tissue samples were traces in the sand tailings. Overall, Arsenic (As) in soil was less than 1ppm but the values increased with increasing depths (Table 1). Thus, the small roots showed levels more than 12 mg/kg which can be classified as a very good Phytoremediation at more than 80 cm depth. Arsenic is readily absorbed by iron oxides and oxyhydroxides at low or neutral pH[12] reducing its mobility. Thus, in low pH conditions where Fe hydroxides are present, mobility and bioavailability of As is reduced.[13]

Conclusion

We may conclude that A. mangium absorbed best both Al and Fe compared with other elements. Zinc and As were moderately absorbed by A. mangium in the tin tailings. Other elements were poorly absorbed or were in trace concentrations and negligible. It is advised that tin tailings such as in the RHT area is afforested with Acacia mangium. This is because Acacia mangium is an important species for Phytoremediation, and its ability to have high bio concentration factor (BCF) and conducive for heavy metal translocation. Overall, of forestation of ex-mining sites should be actively promoted as it creates new value in terms economy and ecology. These areas can also be used for development of new forests and as potential sites for alternative crops.

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Conflict of interest

The authors declared there is no conflict of interest.

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