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Analysis of Plant and Soil from Alum Sludge Farm of Drinking Water Treatment Plant

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ABSTRACT

Drinking water treatment plants which use alum as flocculants in their process have generated a large volume of alum sludge at the end of the treatment process. A study was conducted to analyze the concentration of alum and screen potential plant species in one alum sludge in Putrajaya, Malaysia. *Cyperus haspan* had shown the highest values of Bioaccumulation Absorption Coefficient (BAC) which was 0.37±0.12, but the translocation factor was only 0.13±0.03. *M. micrantha* H.B.K. showed the highest value of TF with 0.44±0.38. The age of sludge showed no significant difference (p>0.05) on the BAC value, except for *Erechtites valerianifolia* and there was no significant difference of TF value (p>0.05) for all plants. Hence, *Cyperus haspan* was a potential species to be used in the phytoremediation of alum sludge in future.

Key words: Alum sludge, phytoremediation, hyperaccumulator, drinking water treatment plant

INTRODUCTION

A typical conventional treatment process in drinking water treatment plant is a series of process consists of rapid mixing, slow mixing sedimentation, filtration and chlorination. In one of the stages, the coagulation-flocculation process, coagulants, such as alum (WHO, 1998) and ferric is added to produce positive charge and then to further neutralize the natural electrical charge on the colloidal particles (Srinivisan *et al.*, 1999). Following this, the water enters the flocculation chamber, together with chemical substance added as flocculants, depending upon the characteristic of raw water and the level of achievement for treatment. In the flocculation chamber, small colloidal particles are brought together to form larger particles as flocs and carried to a clarifier. In the clarifier, the gravity effect causes the formed flocs to settle to the bottom of the tank. Large amount of formed flocs with larger particles combine and become sludge, and they will be pumped out from the tank for disposal. The formed flocs with small particle are carried together with raw water to the filtration stage and washout within the filtration process (Ministry of Health, 2005).

Throughout, these processes, sludge is generated from the treatment process as water treatment residuals (Sotero-Santos *et al.*, 2005). Water treatment residual, also known as alum sludge, is commonly considered as waste product and disposed in landfills, sanitary sewers, or in lagoons (Ippolito *et al.*, 2002). The water treatment residuals are considered as soil amendment due to its ability for P-sorbing. However, water treatment residuals containing Al and Fe can cause P deficiencies in soils and thus, reduce crop yields (Bugsbee and Frink, 1985).

Aluminum released from drinking water treatment plant accumulates in soil and in turn adversely affects the agro-ecosystem (Mcllveen and Negusanti, 1994). The toxic metal contamination of ground water and soil therefore, requires an effective and affordable attention for treatment. Metals, in general, cannot be biologically changed to more or less toxic products and hence, will be persistent in the environment (Wani *et al*., 2007). More researches have concentrated on the effective, less expensive and environment friendly methods for immobilizing heavy metals in contaminated soil, as a form of modification to make them less bioavailable. One of the currently researched soil decontamination methods for heavy metal polluted matter was phytoremediation, which constitutes the use of plants to accumulate heavy metal contaminants (phytoextraction) and also to restrict their dissemination from polluting source (phytostabilization) (Smith and Bradshaw, 1979; Kumar *et al*., 1995). Phytoremediation is a technology that uses plants to clean contaminated sites. It involves the application of information that has been known for years in agriculture to discern environmental problems (Adams *et al*., 2000).

This study aims to screen for potential plants and analyze aluminum concentration in an alum sludge farm of a drinking water treatment plant. The potential plants will be further used in the phytoremediation of alum sludge.

MATERIALS AND METHODS

Formula of calculation: Each plant has a different ability to accumulate metal in the sludge to the whole plant. The ability of the plant is measured through the Biological Absorption Coefficient (BAC). BAC is defined as the ratio between the concentrations in the whole plant and the concentration in the medium like soil or sludge (Dinelli and Lombini, 1996; Roca and Vallejo, 1995). BAC is determined as:

$$BAC = \frac{CP}{CS} \qquad (1)$$

where, CP is the heavy metal concentration in the whole plant and CS is the heavy metal concentration in the sludge. The value of BAC >1 is categorized as the accumulator and BAC <1 as the excluder (Bu-Olayan and Thomas, 2009). According to Nagaraju *et al*. (2006), BAC values have been classified into five groups: 'intensive absorption' (BAC 10-100); 'strong absorption' (BAC 1-10); 'intermediate absorption' (BAC 0.1-1), 'weak absorption' (BAC 0.01-0.1) and 'very weak absorption' (BAC 0.001-0.01).

Also, each plant has a different ability to transfer metal from roots to shoots. The method for this ability, whereby it transfers the contaminant to the upper part of plant is known as the Translocation Factor (TF). The translocation factor is defined as the ratio between concentrations in parts of plants above the medium and concentration in parts of plant in the medium of soil (Singh and Agrawal, 2007). The calculation for the translocation factor is determined as below:

$$TF = \frac{A}{B} \qquad (2)$$

where, A is the heavy metal concentration in parts of plant above the sludge and B is the heavy metal concentration in parts of plant in the sludge.

The value of TF >1 shows that the plant has the ability to translocate heavy metals from root to shoot while TF <1 indicates that the plant only accumulates heavy metal at the root part (Singh and Agrawal, 2007). Additionally, TF greater than 1 indicates that the plant is suitable for phytoextraction (Fitz and Wenzel, 2002).

The total aluminum mass, or aluminum uptake is required to calculate BAC and TF, total aluminum mass is determined through the following formula:

$$M_{Al}(mg) = \rho_{Al}(mg/g) \times M_P(g) \tag{3}$$

where, M_{Al} is the total aluminum mass, ρ_{Al} is the aluminum concentration in part or the whole plant and M_P is the mass of sample.

Alum sludge sampling: Samplings for potential plants were conducted in a sludge farm in Putrajaya, Malaysia in March 2010. Samples of alum sludge were taken based on the soil layer, age of sludge and sampling days. Three layers of sludge were set to differentiate the aluminum content in the alum sludge. Those were the surface (L1), layer at 10 cm in depth (L2) and layer of 20 cm in depth (L3). Four regions of alum sludge were selected based on the age of sludge generated from the treatment process. Samples of sludge within 2 weeks (S1), 1 month to 2 months (S2), 3 months to 5 months (S3) and 6 months and above (S4) were selected as the four regions of alum sludge. Alum sludge was collected in these four regions and there were three layers for each region. Samples were collected on days 0, 2, 5 and 10.

Plant sampling: Six different species (P1, P2, P3, P4, P5 and P6), were collected from the site according to the specific area determined previously as S2, S3 and S4. Since, S1 was new sludge, there was no plant found in this area. Each species of the selected plant must have at least 5 plants and more. Three replicate samples for each species were collected from each site of S2, S3, and S4. The samples were then stored and transported in plastic bags to the laboratory for detailed analysis.

Pretreatment of sludge and plant: Samples of alum sludge and plant collected from the field were washed under running tap water to remove adhered soils, and then they were separated into parts including roots, shoots, leaf, and also fruit and flower for the plants which had them. The samples were dried in an oven (Heraeus UT20, Germany) for 48 h at 80°C. The dried samples were transferred to polyethylene bags for storage for further analysis. The soil samples were air-dried at room temperature for two weeks.

Analysis of alum sludge: One gram of alum sample was placed on the evaporator dish on a hot plate (Favorit HS070V2, Malaysia). 5 mL of HNO_3 (Merck, Germany) and 5 mL of deionized water were added to the evaporator dish. The sample was heated until the solution evaporated to 1 mL of solution remaining in the dish. Later, the deionized water was added until 50 mL. Solution was filtered to separate the sediment. The analysis of aluminum content in alum sludge samples was conducted using the Inductively Coupled Plasma Mass Spectrometer (Perkin Elmer SCIEX ELAN 9000, US).

Plant analysis: The roots and shoots of different plants were analyzed separately for aluminum content. Fraction plant samples of 0.2 g was weighed on porcelain crucibles and heated in a furnace

(Thermo Concept KL05/11, Germany) for 6 h at a temperature between 450-500°C. Grey white ash was obtained at the completion of the ashing. The ash samples were allowed to cool and then, 5 mL of HNO_3 and 5 mL of deionized water were added to each sample. The solution was evaporated to near dryness on a hot plate. The solution was then filtered into 50 mL volumetric flask. Both the crucible and the filter paper were washed into the flasks, made up with deionized water and then stored in polyethylene tubes for aluminium analysis using ICP-MS (Perkin Elmer SCIEX ELAN 9000, US).

Statistical analysis: All the experimental data were subjected to an analysis of variance (ANOVA) using the SPSS, version 16.0 (IBM, USA) software. One Way ANOVA combined with post-hoc multiple comparisons of the means using the Least Significant Difference (LSD) method test at a 95% confidence level or $p \leq 0.05$ was used to evaluate significant aluminum concentration by layers and sampling days, dry weight, aluminum concentration in plant, total mass of aluminum in plant, BAC and TF by different plant species and ages of sludge.

RESULTS AND DISCUSSION

Aluminum content in alum sludge: From Fig. 1, although, the aluminum concentration showed a reduction or an increase from region S1 to regions S2, S3 and S4, all sampling days of alum sludge showed the average aluminum concentration changing from 21.2±1.1 mg g^{-1} in S1 to 22.3±1.7 mg g^{-1} in S2, 22.1±3.7 mg g^{-1} in S3 and 24.6±2.3 mg g^{-1} in S4. In Region S1, the aluminum concentration in sludge showed significant difference between Sampling day for L1 and L3 on Sampling day-2, while other days showed constant value. Significant difference for the aluminum concentration between layers was only at Sampling day-10. In Region S2, the aluminum concentration in the sludge showed significant difference between the Sampling day for all layers only on Sampling day-2, whereas other days showed constant value. Significant difference for aluminum concentration between layers was only on Sampling day-2. In Region S3, aluminum concentration in sludge showed significant difference between Sampling day for all layers for all sampling days. Significant difference for aluminum concentration between layers was found on all sampling days. In Region S4, the aluminum concentration in the sludge showed significant difference between Sampling day for all layers. The aluminum concentration in the sludge showed significant difference on day-2 and day-10, day-2 and day-5, and day-2 for L1, L2 and L3, respectively. Significant difference for aluminum concentration between layers was found only on Sampling day-10.

From the explanations, the results showed that aluminum concentration in alum sludge farm S3 showed significant difference between L1 until L3 on all sampling days. All layers in the alum sludge farm S3 showed significant change from day-0 until day-10. These result showed that the mobility of aluminum was highest in various depths of layers for the alum sludge for 3 to 5 months of age. For the conclusion, the highest aluminum concentration for the alum sludge was over 31.0±1.0 mg g^{-1}. The lowest aluminum concentration for the alum sludge was 17.3±1.0 mg g^{-1}. The average aluminum concentration for samples of alum sludge is 22.6±2.6 mg g^{-1}. A report by Mahdy *et al.* (2008) states that total aluminum concentration in sludge, generated from drinking water treatment plant is around 38.0 mg g^{-1}. Another report from Lin and Green (1990) has stated that total aluminum concentration in alum sludge is around 27.8 mg g^{-1}. Cornwell *et al.* (1992) have further reported that alum sludge from three different water treatment plants contain aluminum concentration with values about 107.0, 123.0 and 28.6 mg g^{-1}. Aluminum normally

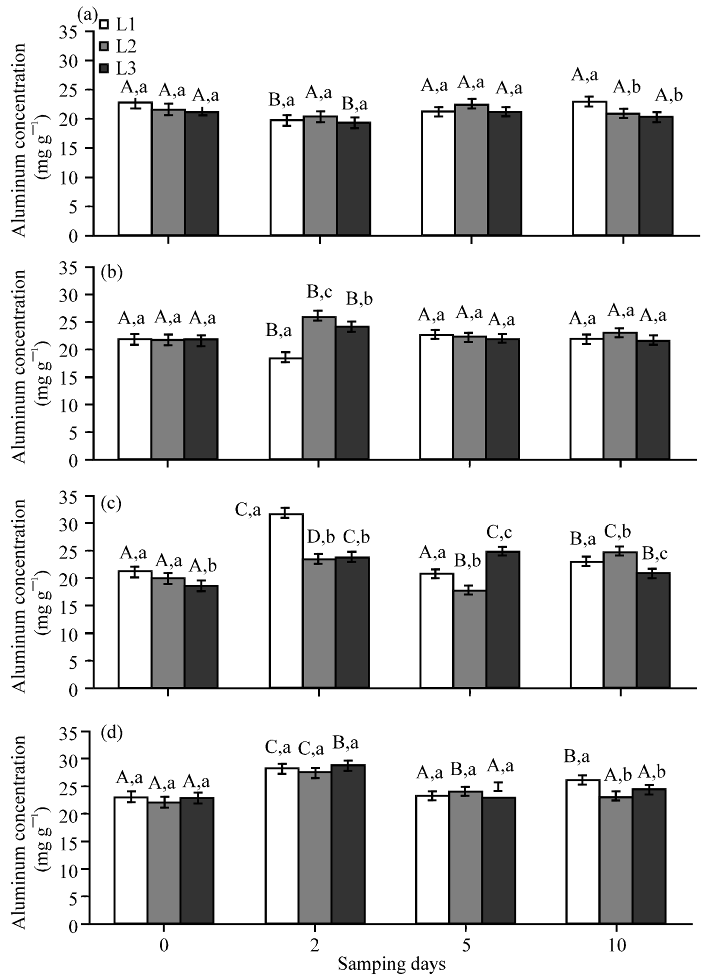

Fig. 1: Variation of aluminum concentration of L1 to L3 on all sampling days for all regions. S1, S2, S3 and S4 refer to sample sludge within 2 weeks, 1 to 2 months, 3 to 5 months and 6 months above, respectively, the same letter means no significant variation at p>0.05 (A denotes significance in sampling days, a denotes significance in layers)

hydrolyzes in a solution form of trivalent Al species Al^{3+}, which dominates in acid conditions with pH<5. Species forms of $Al(OH)^{2+}$ and $Al(OH)_2^+$ cause the pH to increase. At neutral pH, $Al(OH)_3$ occurs in solid phase. $Al(OH)_4$ or aluminate cause an alkaline condition (Delhaize and Ryan, 1995). Soil acidification had caused mobility and phytotoxic of Al in the soil solution (Taylor *et al*., 1989). Differences of aluminum concentration between layers are most probably caused by the rainfall effect especially the acidic rain. Acidic rain normally contains acid sulfuric and extracts aluminum from insoluble form to soluble form through the aluminum hydroxide neutralization process (Bugsbee and Frink, 1985). The higher aluminum concentration in the sludge, the higher the concentration of the aluminum extract from the sludge and the more dissolved it is in water during rainfall. The higher concentration of aluminum may cause more inhibition of plant growth and then may limit the application of plant for remediation (USEPA, 2000). Plants play important role in affecting the soil by their ability to lower the pH and oxygenate the sediment, which altogether affects the availability of the metals (Fritioff and Greger, 2003).

Table 1: Species and photos for selected plants

Plant	Family	Genus	Species
1	Cyperaceae	*Cyperus*	*Cyperus haspan*
2	Cucurbitaceae	*Melothria*	*Melothria affinis King*
3	Asteraceae	*Erechtites*	*Erechtites valerianifolia*
4	Asteraceae	*Mikania*	*Mikania micrantha* H.B.K
5	Asteraceae	*Ageratum*	*Ageratum conyzoides* L.
6	Scrophulariaceae	*Scoparia*	*Scoparia dulcis* L.

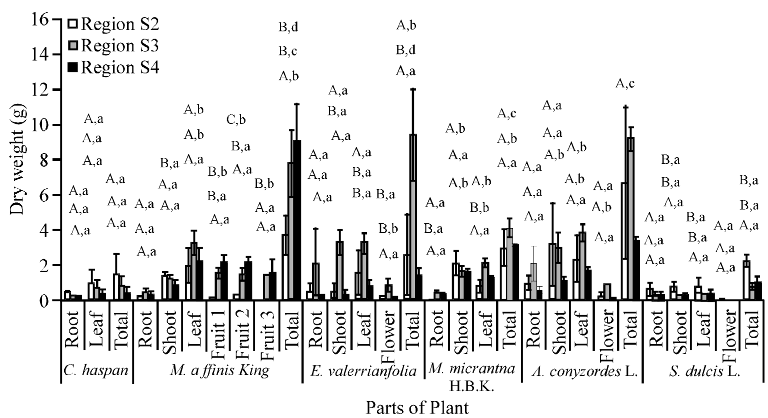

Fig. 2: Dry weight of plant samples for P1 to P6. The same letter means no significant variation at p>0.05 ('A' denotes significance in regions compared to S2, 'a' denotes significance in parts of each plant compared to the root). The total dry weight for all plants had been compared to *C. haspan*. Arrangements started from S2 at below, S3 at the center and S4 at the bottom

Plant sampling: Six plant species (P1, P2, P3, P4, P5 and P6), collected from the alum sludge farm were shown in Table 1. Those plants were identified as *Cyperus haspan*, *Melothria affinis king*, *Erechtites valerianifolia*, *Mikania micrantha* H.B.K, *Ageratum conyzoides* L. and *Scoparia dulcis* L. (Table 1).

Plant analysis for aluminum concentration and total mass aluminum: From Fig. 2, the average total dry weight for *E. valerianifolia* was 9.4±2.6 g in Region S3, followed by *Ageratum conyzoides* L., which had the total dry weight of 9.1±0.6 g in Region S3. The total dry weights of *C. haspan* and *S. dulcis* L. were low, compared to the weights of other four species of plants which were at the range of 1.0-2.0 g. Different age of sludge had demonstrated total dry weight of plants with different value.

For *C. haspan*, the dry weight of this plant was highest at the shoot, with a total average of 0.6±0.5 g, for all plants selected from all regions of S2, S3 and S4. The average total dry weight for *C. haspan* was approximately 0.9±0.8 g. For *M. affinis king*, the dry weight of plant was highest at the leaf, which was around 2.4±0.9 g, compared to other parts in the plants with the average total dry weight of 6.8±2.8 g. *E. valerianifolia* showed the highest dry weight at the leaf which was 1.8±1.3 g with the average total dry weight of 4.4±4.1 g. *M. micrantha* H.B.K. had the highest dry weight at the shoot, which was around 1.7±0.5 g with an average total dry weight of 3.4±0.8 g in approximation. *Ageratum conyzoides* L. showed the highest dry weight at the leaf, which was 2.6±1.2 g, compared to other parts. The average total dry weight for this species was around 6.3±3.3 g. For *S. dulcis* L., the shoot showed the highest dry weight, which was 0.5±0.3 g, compared to other parts of the plant. The average for the total dry weight was 1.3±0.7 g.

C. haspan showed that the total dry weight decreased slightly from S2 until Region S4, indicating that the total dry weight for *C. haspan* showed no significant difference at all regions. For *M. affinis king*, the total dry weight had increased from Region S2 to Region S4 significantly. *E. valerianifolia*, *M. micrantha* H.B.K. and *A. conyzoides* L. had an increased total dry weight from Region S2 to Region S3 and decreased at Region S4, and *E. valerianifolia* was showing significant difference of the total dry weight. For plant *S. dulcis* L., the total dry weight was the highest at Region S2, compared to Region S3 and S4 with significant difference. The result above showed that the age of sludge affecting the total dry weight of plant only applied to species *M. affinis king*, *E. valerianifolia* and *S. dulcis* L.

The aluminum concentrations in each part of the plant for each species are as depicted in Fig. 3. All plant species have a different ability to uptake aluminum. Root of *C. haspan* had the highest average aluminum concentration of 24.3±9.8 mg g^{-1}, but its leaf gained aluminum concentration around 3.0±1.0 mg g^{-1}. From Fig. 3, aluminum concentration in root and leaf showed no significant difference between all regions S2, S3 and S4. Region S2 showed the lowest aluminum concentration in both parts, as compared to regions S3 and S4. The root and leaf of *Cyperus haspan* showed significant difference.

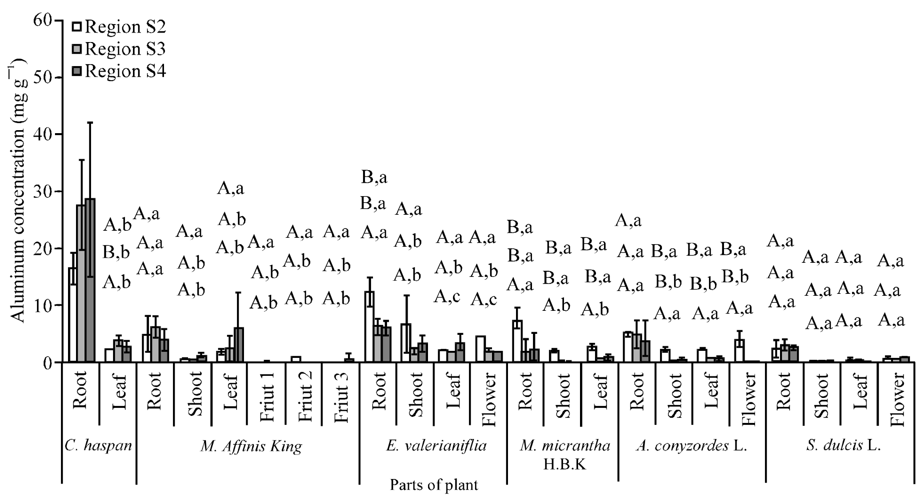

Fig. 3: Aluminum concentration for all parts of plants .The same letter means no significant variation at p>0.05 (A denotes significance in regions compared to S2, a denotes the significance in parts of each plant compared to the root) Arrangements started from S2 at below, S3 at the center and S4 at the bottom

M. affinis King had highest aluminum concentration at the roots, which was 5.0±2.3 mg g^{-1}, compared to other parts of the plant. For the shoot, the concentration was 0.8±0.5 mg g^{-1}, and the leaf gained aluminum concentration of 3.5±4.0 mg g^{-1}. From Fig. 3, the aluminum concentration in all parts showed no significant difference between all regions. Aluminum concentration in all parts of the *M. affinis king* showed significant difference.

E. valerianifolia gained highest aluminum concentration in its root, which was 8.3±3.5 mg g^{-1}, followed by that in its shoot, 4.0±3.4 and leaf, 2.6±1.0 mg g^{-1}. From Fig. 3, aluminum concentration had shown significant difference between the regions only at the roots. The aluminum concentration in the shoot, leaf and flower showed no significant difference between the regions. The aluminum concentration in all parts of *E. valerianifolia* showed significant difference.

M. micrantha H.B.K. gained aluminum concentration of 4.0±3.4 mg g^{-1} at the root, 0.8±0.9 mg g^{-1} at the shoot and 1.4±1.1 mg g^{-1} at the leaf. From Fig. 3, aluminum concentration in the plant showed no significant difference between the regions for the root, and significant difference at the shoot and leaf. Aluminum concentration in all parts of *M. micrantha* H.B.K. showed significant difference.

A. conyzoides L. gained aluminum concentration at the root of 4.6±2.4 and 1.0±1.0 mg g^{-1} for the shoot and 1.3±0.9 mg g^{-1} at the leaf. From Fig. 3, the aluminum concentration at the root was almost constant at all regions. The aluminum concentration at the shoot, leaf and flower showed significant difference between the regions. The aluminum concentration was found to have significant difference at all parts of the plant.

S. dulcis L. gained the lowest aluminum concentration for all parts of the plant compared to other species. The aluminum concentration at the roots was only 2.7±1.0 mg g^{-1}. The shoot gained aluminum concentration of 0.2±0.1 mg g^{-1}, while the leaf gained 0.4±0.2 mg g^{-1}. Although, the shoot and leaf gained low concentration of the aluminum, the flower gained aluminum concentration higher than the shoot and leaf, indicating that *S. dulcis* L. had the ability of transporting aluminum to its upper parts. *S. dulcis* L. showed that the aluminum absorption remained at a constant rate at all parts of the plant, and at all regions. The aluminum concentration was found to have a significant difference at all parts of the plant.

The higher aluminum concentration, the higher the aluminum content will be gained inside the plants. This fact is proven in Fig. 4. Different ages of sludge showed different values of aluminum concentration for each species, especially at the root of the plant. The aluminum concentration increased when the age of alum sludge increased further indicating that the plants were accumulating aluminum.

According to Fig. 4, the profile of the graph was almost similar to Fig. 2. For *C. haspan*, the aluminum uptake at the root part, with an average of 4.5±4.3 mg, was seen to be higher than the leaf part, 1.8±1.6 mg, although the part of the leaf had higher dry weight. From Fig. 4, the aluminum uptake decreased at the roots from regions S2 to S4 and considered constant between the regions. The aluminum mass in the leaf showed the highest at Region S3 and this was constant between regions. The total aluminum mass in the plant was found with the average of 6.3±5.6 mg, which was considered constant between regions.

For *M. affinis king*, roots gained an average aluminum uptake of 1.7±1.6 mg, for the upper part, part of the leaf showed the highest aluminum uptake, which was 7.4±6.6 mg. *M. affinis king* showed the ability to absorb higher aluminum content in the leaf among the upper parts of the plant. Aluminum mass in the root, shoot, leaf, fruit 2 and fruit 3 were constant between regions. Only fruit 1 showed a significant change. The total aluminum mass was found with the average of 10.3±7.5 mg, which was constant between regions.

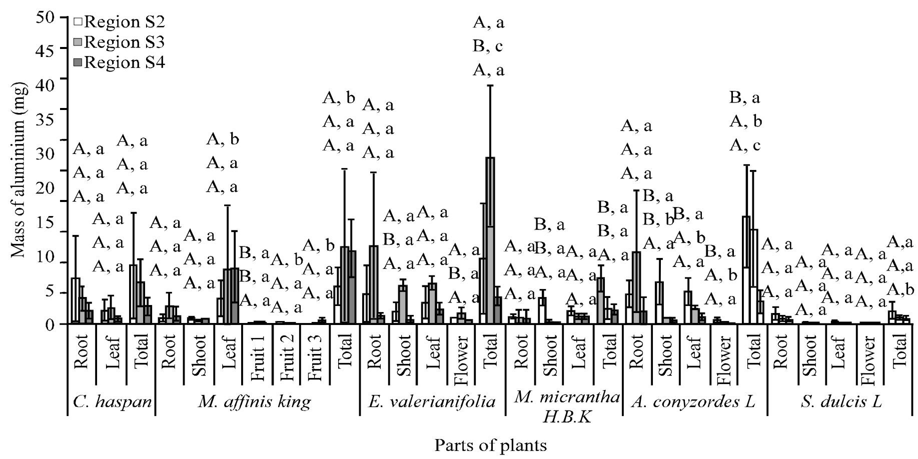

Fig. 4: Total mass of aluminum in plant parts of all species. The same letter means no significant variation at $p>0.05$ ('A' denotes significance in regions compared to S2, 'a' denotes significance in parts of each plant compared to the root). The total aluminum mass for all plants was compared to *C. haspan*. Arrangements started from S2 at below, S3 at the center and S4 at the bottom

For *E. valerianifolia*, roots gained the highest aluminum content compared to other parts of the plant, with the average of 6.3±8.1 mg. It showed the highest total dry weight and aluminum uptake for all parts of the plant in region S3. Aluminum mass in the root and leaf showed no significant variations between regions, while aluminum mass in the shoot and flower showed significant difference. Only shoot and flower showed significant change between regions S2, S3 and S4. Total aluminum mass was calculated with the average of 14.1±12.6 mg, showing significant change between regions.

M. micrantha H.B.K. showed that the aluminum uptake was almost similar in all parts of this plant, with the average of 1.0±0.9, 1.6±2.1 and 1.5±0.7 mg for root, shoot and leaf, respectively. The aluminum mass in root and leaf was constant between regions, while aluminum mass in the shoot showed significant difference between regions. Only the shoot of *M. micrantha* H.B.K. showed significant change between regions. The average total aluminum mass of 4.1±2.9 mg, showed significant change between regions.

A. conyzoides L. showed the highest aluminum uptake at its root with the average of 6.2±6.8 mg, compared to 2.7±3.6 mg for the shoot, 3.0±2.2 mg for the leaf and 0.3±0.4 mg for the flower. *A. conyzoides* L at region S2 showed that the aluminum uptake was highest in the upper parts of the plant. Region S3 showed that the aluminum content in the root was the highest but the aluminum content in the upper part was low. Region S4, showed all parts of plant with low aluminum uptake. The aluminum mass in root and flower was constant between regions, while the aluminum mass in the shoot and leaf showed significant difference. The total aluminum mass was calculated as 12.2±9.3 mg for average, showing constancy between regions.

S. dulcis L. showed the highest aluminum uptake in its root, with the average of 1.0±0.8 mg. All upper parts of this plant showed low aluminum uptake. The aluminum mass in all parts of the plant was constant between regions. The total aluminum mass was calculated with the average of 1.3±1.0 mg, in fact that it was constant and there was no significant variation between regions.

E. valerianifolia had the highest average aluminum mass of 27.2±11.6 mg at Region S3. For the root, *C. haspan* had the highest average total aluminum around 7.3±7.0 mg at Region S2. *A. conyzoides* L. had the highest average total aluminum content of 6.8±3.9 and 5.2±2.4 mg at Region S2 with regards to the shoot and leaf parts. In overall, *E. valerianifolia* gained the highest total aluminum content in the whole plant samples approximated to 14.1±12.6 mg. followed by *A. conyzoides* L., 12.2±9.3 mg, *M. affinis King,* 10.3±7.5 mg, *C. haspan*, 6.3±5.6 mg, *M. micrantha* H.B.K. which was 4.1±2.9 mg and *S. dulcis* L. which was only 1.3±1.0 mg. Age of sludge effect towards aluminum uptake in plants had managed to demonstrate significant difference, only for species *E. valerianifolia* and *M. micrantha* H.B.K. For the selection of plant, the higher aluminum concentration for the plant was considered for phytoremediation. From Eq. 3, the aluminum uptake was limited by the mass of plant. Generally, aluminum in plants comes in the form of Al^{3+}, because plants can only absorb free aluminum ion with pH below than 5 (Loboda and Wolejko, 2006; Ma *et al*., 2001). Al toxicity has been shown to bring effect towards growth inhibition and the reduction of biomass production (Rafia and Hasan, 2008). Residence time directly relates to the bioavailability of metals, indicating that metal can be used by organisms in mediums like soils (Pedersen *et al*., 2000; Joner and Leyval, 2001; Alexander, 2000). Generally the bioavailability of metals in medium decreases with the increasing residence time in medium, indicating that higher age of medium decreases the bioavailability of metals in the medium (McLaughlin, 2001). The ability of plant to uptake metal depends on the bioavailability of the metal in the water phase, which in turn depends on the retention time of the metal. In addition, uptake metal by plant depends on the interaction with other elements and substances in the water (Fritioff and Greger, 2003).

From Fig. 5, all species of plants showed the value BAC to be below than 0.5. *C. haspan* showed that the highest values of BAC were 0.31±0.09 in S2, 0.41±0.10 in S3 and 0.36±0.20 in S4 with the average overall of 0.36±0.10. *E. valerianifolia* had the BAC values of 0.22±0.05 in S2, 0.13±0.02 in S3, 0.14±0.02 in S4 with the average value of 0.16±0.05; *A. conyzoides* L. had BAC

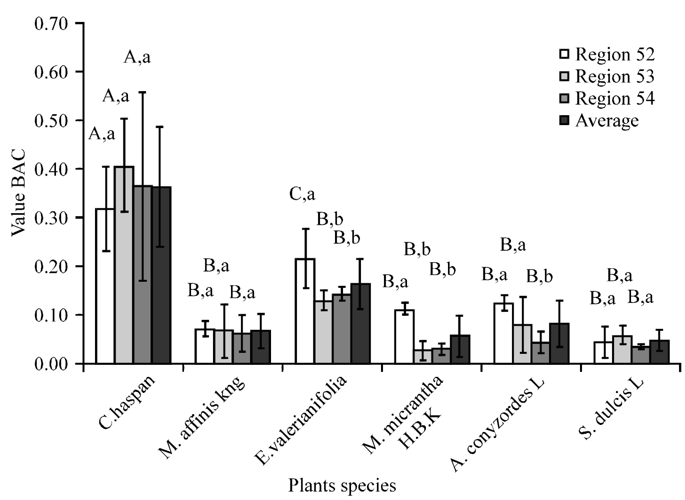

Fig. 5: Biological Absorption Coefficient (BAC) of all species. The same letter means no significant variation at $p>0.05$ ('A' denotes the significance in difference species of plants compared to *C. haspan*, 'a' denotes the significance in regions compared to S2)

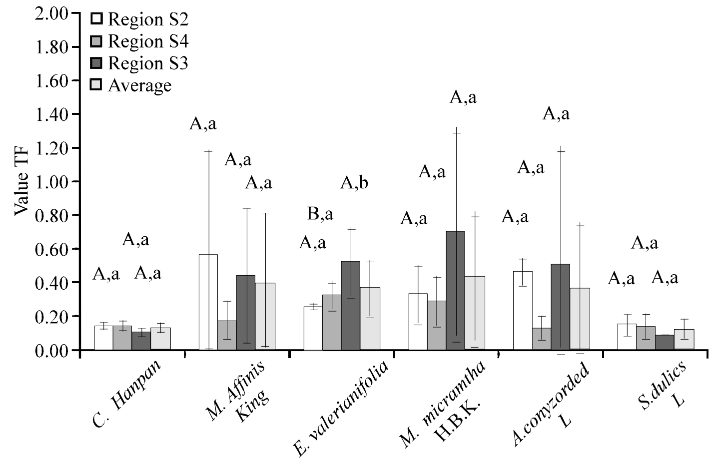

Fig. 6: Translocation Factor (TF) of all species. The same letter means no significant variation at p>0.05 ('A' denotes the significance in difference species of plants compared to *C. haspan*, 'a' denotes the significance in regions compared to S2)

values of 0.13±0.02 in S2, 0.08±0.06 in S3, 0.04±0.02 in S4 and the average value of 0.08±0.05. *M. affinis King* had BAC values of 0.07±0.02 in S2, 0.07±0.05 in S3, 0.06±0.04 in S4 with the average value of 0.07±0.05. *M. micrantha* H.B.K. had BAC values of 0.11±0.01 in S2, 0.03±0.02 in S3, 0.03±0.02 in S4 with 0.06±0.05 for the average value. *S. dulcis* L. had BAC values of 0.05±0.03 in S2, 0.06±0.02 in S3, 0.04±0.02 in S4 with 0.05±0.02 for the average value. The result showed that ability of *C. haspan* to accumulate the aluminum from the sludge was the highest. *C. haspan*, *M. affinis King*, *E. valerianifolia*, *A. conyzoides* L. and *S. dulcis* L. showed a constant value between regions. The age of sludge showed significant difference of BAC, only for the species *M. micrantha* H.B.K.

From Fig. 6, all plant species showed TF value below than 1. *M. Micrantha* H.B.K. showed the highest TF value of 0.70±0.60 in S4, compared to 0.42±0.20 in S2 and 0.40±0.15 in S3. The average value for TF of *M. Micrantha* H.B.K. was 0.44±0.40, followed by *M. affinis King* 0.56±0.60 in S2, 0.18±0.12 in S3, 0.44±0.40 in S4 with the average value of 0.40±0.42. TF values of *E. valerianifolia* were 0.26±0.02 in S2, 0.32±0.10 in S3, 0.52±0.20 in S4 with the average value of 0.36±0.15. *A. conyzoides* L. had TF values of 0.46±0.10 in S2, 0.14±0.10 in S3, 0.50±0.10 in S4 with the average value of 0.36±0.40. *C. haspan* had TF values of 0.14±0.02 in S2, 0.14±0.05 in S3, 0.10±0.02 in S4 with the average value of 0.14±0.05. *S. dulcis* L. had TF values of 0.14±0.05 in S2, 0.14±0.05 in S3, 0.10±0.00 in S4 with 0.12±0.05 for the average value. *C. haspan*, *M. affinis King*, *E. valerianifolia*, *M. micrantha* H.B.K, *A. conyzoides* L. and *S. dulcis* L. showed no variation between regions, indicating that the age of sludge had no effect on the significant change of the TF value for all species of plants.

The overall average of TF for *M. Micrantha* H.B.K. was the highest but the BAC value was only 0.06±0.05. Although, *C. haspan* showed the highest BAC, which can accumulate highest aluminum from the sludge, the translocation factor was noted between 0.1 and 0.2. *S. dulcis* L. showed the lowest value for both BAC and TF.

Based on Fig. 7, the overall average of aluminum concentration was shown and compared with the results obtained by Xie *et al.* (2001), who did a research on an abandoned tea plantation for

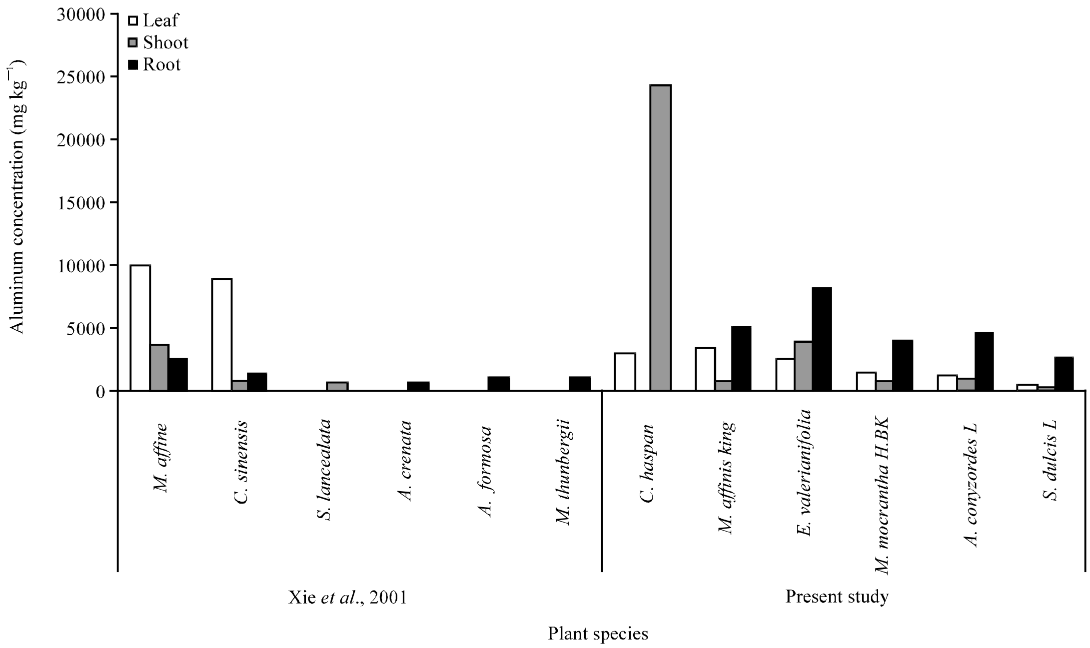

Fig. 7: Comparison of Aluminum Concentration with the findings by Xie *et al.* (2001)

aluminum and fluoride concentrations in selected species of plants. *M. affine* showed the highest aluminum for leaf which was 9932 mg kg^{-1}, 3654 mg kg^{-1} for the shoot and 2564 mg kg^{-1} for the root. For species *C. sinensis,* the aluminum concentration for the leaf was the highest of 8910 mg kg^{-1} for the leaf, 798 mg kg^{-1} for the shoot and 1382 mg kg^{-1} for the root (Xie *et al.*, 2001). These two species had shown the translocation factor above 1. In this study, although, *C. haspan* had shown the highest aluminum concentration which was 25,000±10,000 mg kg^{-1}, the aluminum concentration for leaf was found to be lower 3,000±1,000 mg kg^{-1}. The translocation factor for all species in this review had gone below the 0.5, which means that aluminum accumulated higher on the root part, as compared to other parts of the plant.

For plants considered as accumulators, the aluminum concentration in the leaf of 65 tree species and 12 unidentified trees from an Indonesian rain forest ranged from 1.0 mg g^{-1}, in delta trees (*Aporosa* spp. Blume, Euphorbiaceae) to 37.0 mg g^{-1} in *Maschalocorymbosus corymbosus* Bremek (Rubiaceae) (Masunaga *et al.*, 1998). Aluminum accumulators (*Melastoma malabathricum* L., *Hydrangea macrophylla* Ser. and *Fagopyrum esculentum* Moench.) exposed to the increased aluminum in the solution showed increasing aluminum concentrations in leaves (Osaki *et al.*, 1997).

CONCLUSIONS

The concentration of aluminum have been generated from drinking water treatment with an average of 22.6±2.6 mg g^{-1}. Plants on the alum sludge farms of S2, S3 and S4 play important role by way of affecting the aluminum concentration in the sludge and uptake of aluminum in selected plants. Different abilities for each plant species to uptake aluminum were obtained. All in all, all plants did accumulate aluminum. From the results, *C. haspan* has the potential to be hyperaccumulators for aluminum, with the highest aluminum concentration of 24.3±9.8 mg g^{-1} in the root, 3.0±1.0 mg g^{-1} in the leaf, and the highest value of BAC which was 0.36±0.10, although, the value of TF was low, which was only 0.14±0.05. The potential of adsorbing aluminum is limited by the total mass of the sample. High aluminum concentration and mass of plant sample will gain higher content of aluminum for selected plants. Hence, this study justifies the facts that *C. haspan* is a good candidate for the uptaking of aluminum but this result requires further clarification in the toxicity test.

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REFERENCES

Adams, N., D. Carroll, K. Madalinski, S. Rock and T. Wilson, 2000. Overview of Phytoremediation. In: Introduction of Phytoremediation, EPA (Ed.). Environmental Protection Agency (EPA), USA.

Alexander, M., 2000. Ageing, bioavailability and overestimation of risk from environmental pollutants: Critical review. Environ. Toxicol. Chem., 34: 4259-4265.

Bu-Olayan, A.H. and B.V. Thomas, 2009. Translocation and bioaccumulation of trace metals in desert plants of Kuwait governorates. Res. J. Environ. Sci., 3: 581-587.

Bugsbee, G.J. and C.R. Frink, 1985. Alum sludge as a soil amendment: Effects on soil properties and plant growth. New Haven Connecticut Agricultural Experiment Station Bulletin, 827.

Cornwell, D.A., C. Vandermeyden, G. Dillow and M. Wang, 1992. Sludge physical characterization. Landfilling of Water Treatment Plant Coagulant Sludges, Awwa Research Foundation report. Denver, CO: Water Research Foundation.

Delhaize, E. and P.R. Ryan, 1995. Aluminum toxicity and tolerance in plants. Plant Physiol., 107: 315-321.

Dinelli, E. and A. Lombini, 1996. Metal distributions in plants growing on copper mine spoils in Northern Apennines, Italy: The evaluation of seasonal variations. Applied Geochem., 11: 375-385.

Fitz, W.J. and W.W. Wenzel, 2002. Arsenic transformation in the soil-rhizosphere-plant system, fundamentals and potential application of phytoremediation. J. Biotechnol., 99: 259-278.

Fritioff, A. and M. Greger, 2003. Aquatic and terrestrial plant species with potential to remove heavy metals from storm water. Int. J. Phytoremediation, 5: 211-224.

Ippolito, J.A., K.A. Barbarick and E.F. Redente, 2002. Combinations of water treatment residuals and biosolids affect two range grasses. Commun. Soil Sci. Plant Anal., 33: 831-844.

Joner, E.J. and C. Leyval, 2001. Time-course of heavy metal uptake in maize and clover as affected by root density and different mycorrhizal inoculation regimes. Biol. Fertil. Soils, 33: 351-357.

Kumar, P.B.A.N., V. Dushenkov, H. Motto and I. Raskin, 1995. Phytoextraction: The use of plants to remove heavy metals from soils. Environ. Sci. Technol., 29: 1232-1238.

Lin, S.D. and C.D. Green, 1990. Two-year study of alum sludge application to com and soybean farmland. Illinois State Water Survey, Champaign, Report of Investigation 113. http://www.isws.illinois.edu/pubdoc/RI/ISWSRI-113.pdf

Loboda, T. and E. Wolejko, 2006. Effect of pH and Al^{3+} concentration on growth of spring brewer's barley. Agron. Res., 4: 517-529.

Ma, J.F., P.R. Ryan and E. Delhaize, 2001. Aluminum tolerance in plants and the complexing role of organic acids. Trends Plant Sci., 6: 273-278.

Mahdy, A.M., E.A. Elkhatib and N.O. Fathi, 2008. Drinking water treatment residuals as an amendment to alkaline soils: Effects on bioaccumulation of heavy metals and aluminum in corn plants. Plant Soil Environ., 54: 234-246.

Masunaga, T., D. Kubota, M. Hotta and T. Wakatsuki, 1998. Mineral composition of leaves and bark in aluminum accumulators in tropical rain forest in Indonesia. Soil Sci. Plant Nutr., 44: 347-358.

McLaughlin, M.J., 2001. Ageing of metals in soils changes bioavailability. Environ. Risk Assess., 4: 1-6.

Mcllveen, W.D. and J.J. Negusanti, 1994. Nickel in the terrestrial environment. Sci. Total Environ., 148: 109-138.

Ministry of Health, 2005. Coagulation and Filtration. In: Draft Guidelines for Drinking-Water Quality Management for New Zealand 2005, Ministry of Health (Ed.). 2nd Edn. Ministry of Health, Wellington, New Zealand.

Nagaraju, A., A. Swathi and K. Hudson-Edwards, 2006. *Prosopis juliflora* on barite mine tailings: A case study from Mangampeta region, Cuddapah District, Andhra Pradesh, India. Proceedings of the 10th Billings Land Reclamation Symposium, June 4-8, 2006, Sheraton Billings Hotel, Billings, MT., USA., pp: 580-591.

Osaki, M., T. Watanabe and T. Tadano, 1997. Beneficial effect of aluminum on growth of plants adapted to low pH soils. Soil Sci. Plant Nutr., 43: 551-563.

Pedersen, M.B., C. Kjar and N. Elmegaard, 2000. Toxicity and Bioaccumulation of copper to black bindweed (*Fallopia convolvulus*) in relation to bioavailability and the age of soil contamination. Arch. Environ. Contam. Toxicol., 39: 431-439.

Rafia, A. and S. Hasan, 2008. Photochemistry of light harvesting pigments and some biochemical changes under aluminium stress. Pak. J. Bot., 40: 779-784.

Roca, M.C. and V.R. Vallejo, 1995. Effect of soil potassium and calcium on caesium and strontium uptake by plant roots. J. Environ. Radioactivity, 28: 141-159.

Singh, R.P. and M. Agrawal, 2007. Effects of sewage sludge amendment on heavy metal accumulation and consequent responses of *Beta vulgaris* plants. Chemosphere, 67: 2229-2240.

Smith, R.A.H. and A.D. Bradshaw, 1979. The use of metal tolerant plant populations for the reclamation of metalliferous wastes. J. Applied Ecol., 16: 595-612.

Sotero-Santos, R.B., O. Rocha and J. Povinelli, 2005. Evaluation of water treatment sludge toxicity using Daphnia bioassay. Water Res., 39: 3909-3917.

Srinivisan, P.T., T. Viraraghavan and K.S. Subramanian, 1999. Aluminium in drinking water: An overview. Water South Afri., 25: 47-56.

Taylor, G.J., A.H. Adriano and A.H. Johnson, 1989. Acidic Precipitation: Biological and Ecological Effects. Springer Verlag, New York, USA., pp: 327-361.

USEPA, 2000. Introduction to Phytoremediation. United States Environmental Protection Agency, Washington, DC., USA.

WHO, 1998. Guidelines for Drinking-water Quality. 2nd Edn., World Health Organization, Geneva.

Wani, P.A., M.S. Khan and A. Zaidi, 2007. Effect of metal tolerant plant growth promoting *Bradyrhizobium* sp. (vigna) on growth, symbiosis, seed yield and metal uptake by greengram plants. Chemosphere, 70: 36-45.

Xie, Z.M., Z.H. Ye and M.H. Wong, 2001. Distribution characteristics of fluoride and aluminum in soil profiles of an abandoned tea plantation and their uptake by six woody species. Environ. Exp. Bot., 26: 341-346.