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Assessment of Heavy Metals Uptake and Translocation by *Aquilaria malaccensis* Planted in Soils Containing Sewage Sludge

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ABSTRACT

Increase in human population has resulted in an enormous growth in the volume of wastewater. The conventional methods of sewage sludge disposal, that is the by-product of wastewater treatment, are costly and not environment-friendly. An ideal way for sewage sludge management is by using it as a soil amendment in agricultural land due to sewage sludge's high organic matter content. However, sewage sludge contains high levels of heavy metals that can be harmful to both plants and the environment. Hence, these metals need to be removed before the sewage sludge is to be used as a soil amendment. The objective of this study was to assess the potential of *Aquilaria malaccensis* to uptake and translocate heavy metals found in sewage sludge. *A.malaccensis* seedlings were planted on six different planting media: T0/Control (100% soil), T1 (80% soil and 20% sewage sludge), T2 (60% soil and 40% sewage sludge), T3 (40% soil and 60% sewage sludge), T4 (20% soil and 80% sewage sludge) and T5 (100% sewage sludge) for the duration of 16 weeks. The growth performance of height and basal diameter was measured using diameter tape and venier caliper every two weeks, respectively. The average dry weight biomass of *A.malaccensis* was measured using destructive sampling at 16 weeks after planting. Plant samples were collected after harvest and soil samples were collected before planting and after harvesting. Atomic Absorbtion Spectrophotometer (AAS) was used to determine the concentration of heavy metals in the planting media and the plant parts (leaves, stem and roots). The highest growth of *A.malaccensis* was recorded for the T5 growth media. The highest concentration of Fe in the roots of the *A.malaccensis* plant was in the T5 growth media (2770.75 ppm). The highest accumulation of Zn (95.62 ppm) was recorded in the roots of *A.malaccensis* in the T5 growth media, whereas the stem of the *A.malaccensis* in T5 recorded the highest Cd accumulation (3.75 ppm). The highest Pb uptake was recorded in the roots of *A.malaccensis* in T5 (39.79 ppm), while the lowest accumulation of Pb was noted in the leaves of the *A.malaccensis* in control (16.08 ppm). The highest Translocation Factor (TF) (2.00) for Cd was recorded in T5. The lowest Bioconcentration Factor (BCF) for Cu was recorded at T5 (0.18). The highest TF for Pb was recorded in control (1.50), while the lowest was in T5 (1.23). The BCF for Zn was lowest in T5 (0.64). The *A.malaccensis* plant was found to be suitable for taking up heavy metals from sewage sludge especially Cd and Cu. The roots of *A.malaccensis* are ideal in uptaking and storing Fe, while the stem of the *A.malaccensis* plant is ideal for the uptake and accumulation of Cd. More studies need to be conducted, especially in field conditions, to optimize the potential of the *A.malaccensis* plant as a phytoremediator.

Keywords: *Aquilaria Malaccensis*, Phytoremediation, Heavy Metals, Sewage Sludge, Translocation Factor (TF), Bioconcentration Factor (BCF)

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1. INTRODUCTION

There has been an increased awareness to the importance of green technology to mitigate harms to the environment (Olivier, 2006). This environmental awareness was largely fueled during the 1990's, where climate change issues are becoming more prevalent concerns of the world (Miranda, 2012). Ever since then, there has been increasing evidences leading to believe that human activities are primary causes of environmental damage including climate change (Miranda, 2012). Climate change occurs naturally; however, various human activities have led to climate change happening at an alarming and potentially hazardous pace (Nicholas and Daniel, 2008). These anthropogenic activities include the burning of fossil fuels, the use of chemicals such as inorganic fertilizers, deforestation and waste disposal (Miranda, 2012). In order to combat climate change and potential harms to the environment, green technology is continuously being developed in order to preserve the quality of human life while preserving the environment (Olivier, 2006). One such activity that is currently the focus of green technology development is the disposal of sewage sludge.

Rapid industrialization and urbanization due to the ever increasing human population, has caused the volume of wastewater to increase exponentially (Abdu *et al*., 2011). When wastewaters are treated at wastewater treatment facilities, it produces solid waste products known as sewage sludge (Abdu *et al*., 2011). Malaysia is currently estimated to produce about 5 million cubic meters of sewage sludge per year and the amount has been estimated to reach 7 million cubic meters per year by 2022 (IWK, 1997). Due to the increasing amount of sewage sludge produced is constantly increasing; the disposal of sewage sludge is increasingly becoming a major distress not only to Malaysia, but globally as well (Ghafoori *et al*., 2011). Sewage sludge disposal has also been linked to climate change, since conventional methods of disposing such as burning produces methane. Besides that, other methods of disposal, either by land or sea, has also raised numerous environmental concerns (Abdu *et al*., 2011).

The conventional environment-friendly methods of sewage sludge disposal are very costly, time consuming and requires expertise knowledge (Majid *et al*., 2011). A cost effective and environment-friendly method for sewage sludge management is by using it as a soil amendment in agricultural land (Abdu *et al*., 2011). Sewage sludge has high organic matter content, making it suitable to be used as an organic fertilizer (Singh and Argawal, 2008). Hence, the application of sewage sludge will also reduce the dependency and the need for inorganic fertilizers, making it a very credible environment-friendly option (Majid *et al*., 2011). However, sewage sludge contains high amounts of heavy metals, especially due to industrial wastewater contamination (Raymond and Felix, 2011). Previous studies have also indicated that sewage sludges in Malaysia have very high heavy metal content (IWK, 1997). Therefore, land disposal for extensive periods would result in the accumulation of toxic levels of heavy metal due to heavy metals being non-degradable and dangerous pollutants (Raymond and Felix, 2011).

Heavy metals occur naturally in soil but in non-toxic levels and some of these heavy metals are needed in small amounts by plants and animals (Rascio and Navari-Izzo, 2011). However, heavy metals are not readily metabolized and accumulate in the soft tissues, making it toxic when in high concentrations (Rascio and Navari-Izzo, 2011). Heavy metal, that is chemical elements with a specific gravity that is at least five times the specific gravity of water (Kvesitadze *et al*., 2006), have been characterized by the United States Environmental Protection Agency (USEPA) and state regulation as trace elements that can be harmful to the environment, human, animals and plants. Hence, sewage sludge has the potential to be beneficial to plants due to its high nutrient content; however, indiscriminate usage of sewage sludge as a soil amendment would result in detrimental effects to the plants because of the presence of high amounts of heavy metal, such as Cd, Zn, Fe and Cu (Raymond and Felix, 2011).

There are numerous methods of managing soil contamination such as heavy metals; one such organic method is known as phytoremediation (Majid *et al*., 2011). Phytoremediation is a technology that employs plants to degrade, remove or remediate contaminants from soil (Karen *et al*., 2009). Phytoremediation does not damage soil structure (Purakayastha and Chhonkar, 2010) and is an enviroment-friendly method of removing soil contamination. Plants that are suitable for phytoremediation should have certain selected plants characteristic that is it should be fast growing, has high biomass and a natural tolerance to toxic substances such as heavy metals and salinity (Majid *et al*., 2011). The detoxification potential of the plant is determined by the rate and depth of contaminant uptake from the soil, accumulation in the plant cell and the degree of contaminant transformation to regular cell metabolites (Jos *et al*., 2009).

Plants that are able to accumulate metals without exhibiting signs of toxicity make excellent phytoremediators (Bennett *et al*., 2003). At least 45 plant families and individual species have been identified as hyper metal accumulating plant species, that is have the capability to accumulate different metals (Purakayastha and Chhonkar, 2010). Some of these plant families are Brassicaceae, Fabaceae, Euphorbiaceae, Asteraceae, Lamiaceae and Scrophulariaceae.

For this study, the plant species *A.malaccensis* was selected to determine its potential to clean up toxic heavy metals from sewage sludge. *Aquilaria malaccensis*, (Family: Thymelaeaceae) is commonly known as "karas" is locally found in Indonesia and Malaysia. *A.malaccensis* are widely harvested from the wild due to a highly valuable and commercial resinous wood used as incense Reeves and Baker (2000). This species have been studied extensively on its taxonomy and morphology (Soehartono and Newton, 2000). Studies have also been conducted on *A. malaccensis* reproductive ecology (Soehartono and Newton, 2000). However, there is still a lack of research on the potential of *A.malaccensis* to be used as a phytoremediator species. Hence, the objective of this study was to evaluate the ability of *A.malaccensis* to uptake and translocate the heavy metals from sewage sludge contaminated soil.

2. MATERIALS AND METHODS

2.1. Site Description and Planting Materials

The study was conducted at the greenhouse of University Agriculture Park, Universiti Putra Malaysia (4°062 N latitude and 101°162 E longitude) for 16 weeks (January 2012 to April 2012). Relative humidity in the greenhouse was 65%, while the temperature at greenhouse was 27°C in the morning and 35°C in the evening. The seedlings of the *A.malaccensis* tree were germinated from cuttings of the mature stem and planted in polybags (16.0×16.0 cm) in the Faculty of Forestry nursery. The growing medium for the *A.malaccensis* seedlings were in the proportions of soil: organic matter: river sand in a 3:2:1 ratio. The seedlings were transplanted into suitable plastic pots (32.0 cm height, 106.0 cm upper diameter and 69.0 lower diameter) that were filled up with the mixture of soil and sewage sludge after one month.

2.2. Plant and Soil Sampling

There were six different levels of treatments used in this study, with four replicates for each treatment. The treatment consisted of a mixture of soil and dry sewage sludge and the control consisted of only soil: T0/Control (100% soil), T1 (80 soil and 20% sewage sludge), T2 (60 soil and 40% sewage sludge), T3 (40 soil and 60% sewage sludge), T4 (20 soil and 80% sewage sludge) and T5 (100 sewage sludge). The pots were labelled according to their compositions. The Completely Randomized Design (CRD) was used in this study. Soil samples were collected from each pot before planting and after harvesting. They were then kept in standard plastic containers and air-dried before physico-chemical analyses.

2.3. Soil Analysis

Soil pH was determined by glass-electrode at 1:5 soil to solution ratio after reciprocal shaking for 1 h (Jackson, 1973). Soil samples were collected from each pot before planting and after harvesting, kept in standard plastic containers and air-dried prior chemical analyses. AAS was used for analyzing the concentrations of selected heavy metals [iron (Fe), zinc (Zn), cadmium (Cd), lead (Pb) and copper (Cu)] in the planting media and plant parts and aqua regia was used as the extractant (Sahoo *et al*., 2009). Total carbon was determined using loss on ignition method.

2.4. Plant Growth and Biomass Measurement

The heights, diameters and number of leaves of the *A.malaccensis* plants were measured every two weeks throughout the study period with diameter tape, while the basal diameter was measured using a venier caliper every two weeks. Plant biomass was measured separately according to leaves, stems and roots. The loss in weight upon drying is the weight originally present. The moisture content of the sample was calculated using Equation 1:

$$\%W = \frac{A - B}{B} \times 100 \quad (1)$$

where, %W = percentage of moisture in the sample, A = weight of wet sample and B = weight of dry sample.

Translocation Factor (TF) and Bioconcentration Factor (BCF). The plant's ability to accumulate metals from soils and translocate metals from roots to shoots was estimated using the translocation factor (Equation 2) and the concentration in roots to soil was estimated using bioconcentration factor (Equation 3).

$$TF = \frac{\text{Metal concentration aerial parts}}{\text{Metal concentration in roots}} \quad (2)$$

$$BCF = \frac{\text{Metal concentration in roots}}{\text{Metal concentration in soil}} \quad (3)$$

2.5. Statistical Analysis

The analyses for growth and heavy metals in the soil, sludge and plant parts were done following the Analyses of Variance (ANOVA) technique and the mean values were adjusted using Tukey's as a post hoc test (p≤0.05). A comparison using the Student's t-test at a 5% level was done to detect any significant differences between samples taken before planting and after harvesting. All data were statistically analyzed using the statistical package for SPSS 16.0 program.

3. RESULTS

3.1. General Properties of the Growth Media

The soil texture was found to be silty clay. All treatments initially had low pH (4.39 to 5.56) and it increased at harvest (4.50 to 5.61) (**Table 1**). T3 recorded the highest change in soil pH (5.13 to 5.32). Total carbon of the growth media had a direct correlation with the percentage of sewage sludge in the treatment level; the higher the percentage of sludge in the growth media, the higher was the total carbon of the growth media (**Table 1**). Before planting, the highest total carbon was recorded in T5 (13.33%) and the lowest was in the T0 (0.71%). After harvest, total carbon decreased in all the treatments, except in T0. The maximum total carbon content (6.58%) was found in T5, while the minimum content was recorded in the T0 (1.05%).

3.2. Growth Performance and Plant Biomass

The results in **Table 2** showed significant differences (p≤0.05) among the treatments in terms of total height and basal diameter. *A.malaccensis* planted in the T5 recorded the highest total height (47.55 cm), which was closely followed by the T4 (46.83 cm). The basal diameter showed similar pattern with total height. After week 8, basal diameter was constant for all treatments except for T1 and T2 which increased slightly. Treatment 5 (6.73 cm) showed the highest total basal diameter. After 16 weeks, treatment 5 produced the highest number of leaves (20). As shown in **Fig. 1c**, the lowest number of leaves was recorded by T0 (17). Overall, the numbers of leaves for all treatment levels were almost similar.

Table 1. The pH and total-C (%) content in growth media by different levels of sewage sludge

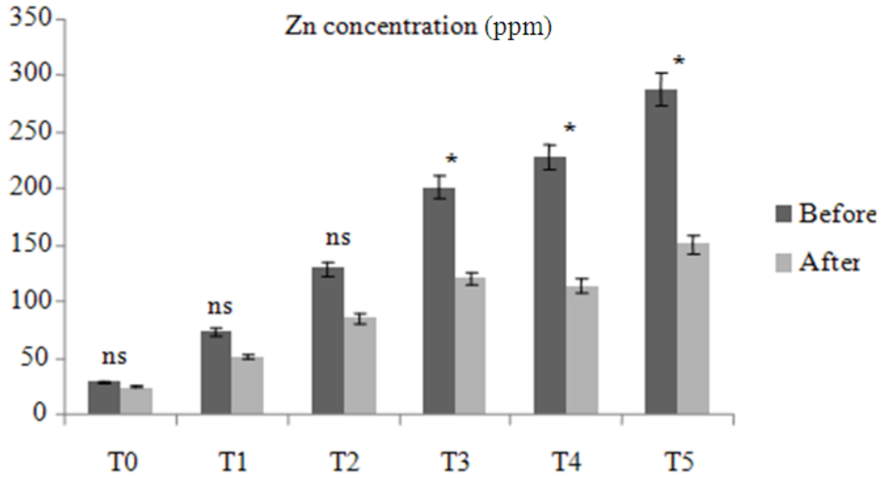
	pH		Total-C	
Treatment	B	A	B	A
T0	4.39±0.04a	4.50±0.16a	0.71±0.07a	1.05±0.11a
T1	4.78±0.16a	4.85±0.14a	1.70±0.55a	1.64±0.68a
T2	4.92±0.05a	5.10±0.09a	4.02±0.68a	2.63±0.16b
T3	5.13±0.37a	5.32±012a	6.15±0.26a	3.00±1.08b
T4	5.39±0.56a	5.48±0.45a	8.65±0.44a	4.53±1.13b
T5	5.56±0.26a	5.61±0.26	13.33±1.32a	6.58±1.50b

Note: Different letter within a column indicate significant differences between means following tukey's test (P ≤0.05); T0-control (100% soil), T1 (80% soil and 20% sewage sludge), T2 (60% soil and 40% sewage sludge), T3 (40% soil sewage sludge), T4 (20% soil and 80% sewage sludge) and T5 (100% sewage sludge); B (before planting), A (after harvesting)

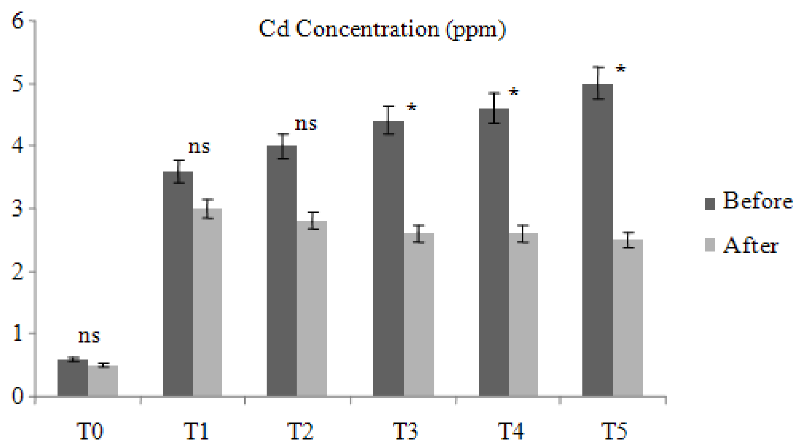
Table 2. Total height, basal diameter and number of leaves for *A. malaccensis* at 16 weeks after planting

Treatment	Height (cm)	Basal diameter (mm)	No. leaves
T0	41.77a	5.46a	16a
T1	43.60a	5.80a	17a
T2	44.23a	6.04a	19a
T3	45.69ab	6.47ab	17a
T4	86.83b	6.53b	18a
T5	47.55b	6.73b	20a

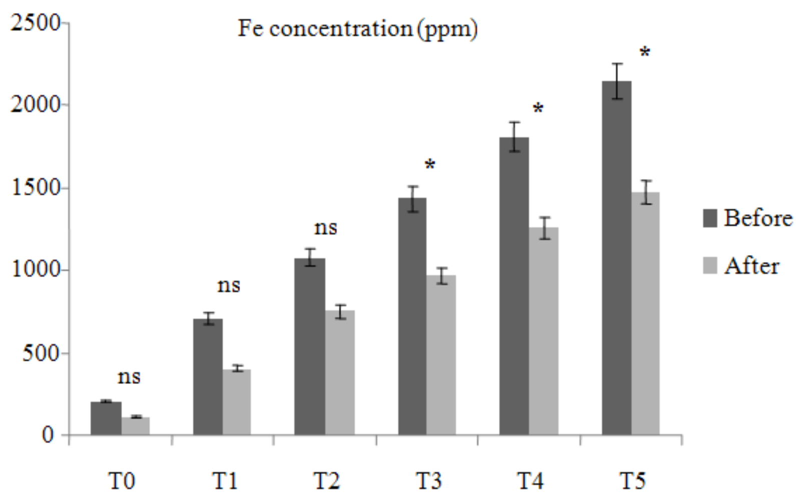
Note: Different letter within a column indicate significant differences between means following tukey's test (P ≤0.05); T0 control (100% soil), T1 (80% soil and 20% sewage sludge), T2 (60% soil and 40% sewage sludge), T3 (40% soil and 60% sewage sludge), T4 (20% soil and 80% sewage sludge) and T5 (100% sewage sludge)


Zn concentration (ppm)
350
300
250
200
150
100
50
0
ns
ns
ns
*
*
*
T0
T1
T2
T3
T4
T5
Before
After

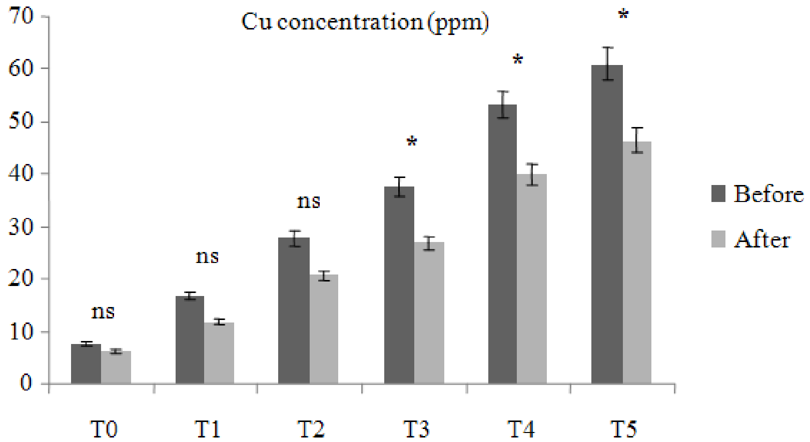
(a)


Cd Concentration (ppm)
6
5
4
3
2
1
0
ns
ns
ns
*
*
*
T0
T1
T2
T3
T4
T5
Before
After

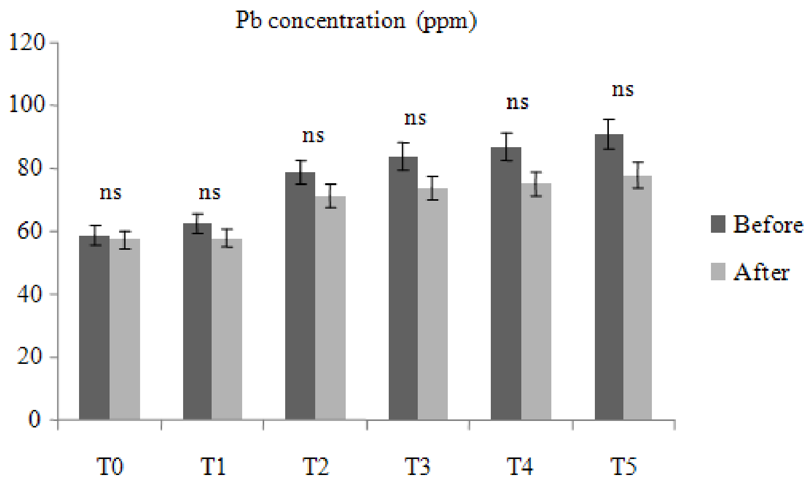
(b)


Fe concentration (ppm)
2500
2000
1500
1000
500
0
ns
ns
ns
*
*
*
T0
T1
T2
T3
T4
T5
Before
After

(c)



(d)



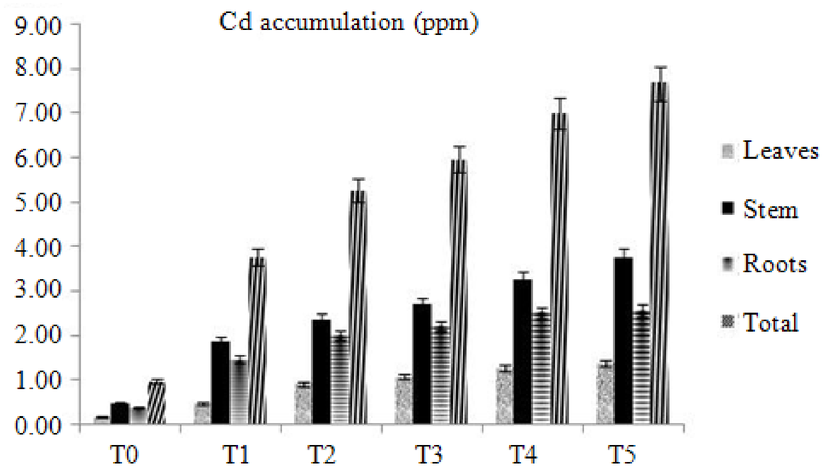
(e)

Fig. 1. The concentrations of Zn (a), Cd (b), Fe (c), Cu (d) and Pb (e) in growth medium before planting and after harvesting. * indicate significant difference between means at each treatment before planting and after harvesting according to a Student's t-test ($p \leq 0.05$), ns indicates no significant difference. T0, (100% soil-control), T1, (80% soil and 20% sewage sludge), T2, (60% soil and 40% sewage sludge), T3, (40% soil and 60% sewage sludge), T4, (20% soil and 80% sewage sludge), T5, (100% sewage sludge)

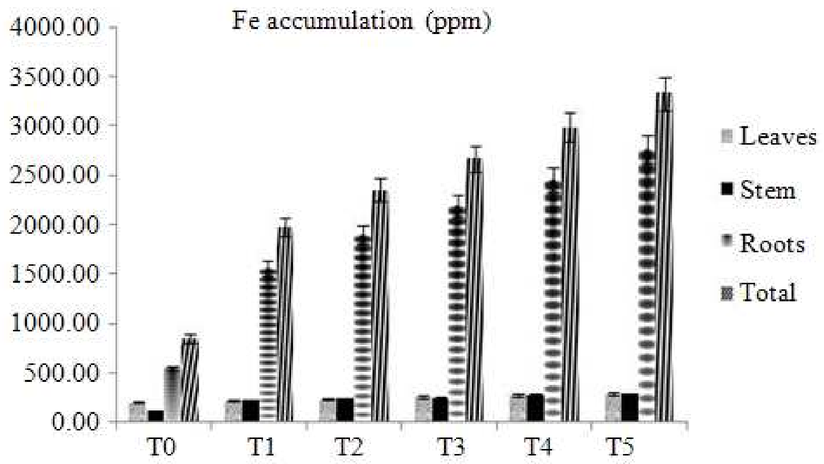
Table 3. Average dry weight biomass for leaves, stem and roots of *A. malaccensis* at 16 weeks after planting

Treatment	Roots	Stem	Leaves
T0	71.88a	63.65a	61.52a
T1	72.19a	64.76a	64.17a
T2	73.17a	65.94a	65.63a
T3	74.38a	67.66a	67.21a
T4	75.06a	67.83a	68.42a
T5	75.18a	70.00a	68.73a

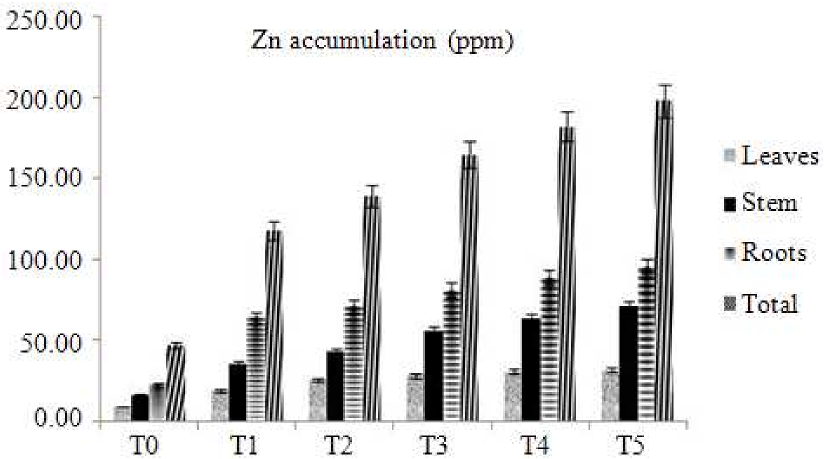
Note: Different letter within a column indicate significant differences between means following tukey's test ($p \leq 0.05$); T0 control (100% soil), T1 (80% soil and 20% sewage sludge), T2 (60% soil and 40% sewage sludge), T3 (40% soil and 60% sewage sludge), T4 (20% soil and 80% sewage sludge) and T5 (100% sewage sludge)


Cd accumulation (ppm)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
T0
T1
T2
T3
T4
T5
Leaves
Stem
Roots
Total

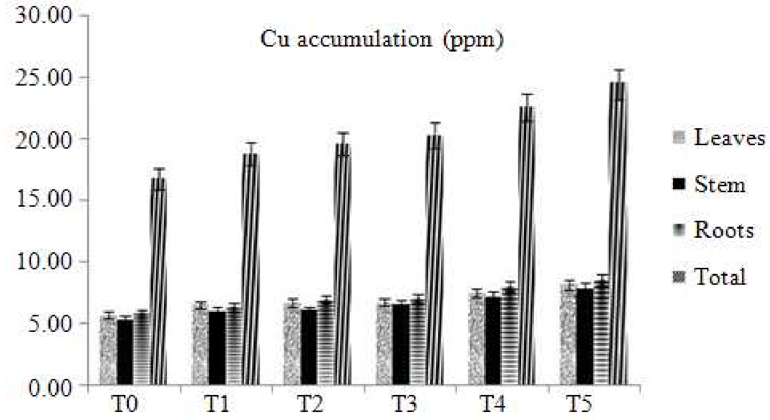
(a)


Fe accumulation (ppm)
4000.00
3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
T0
T1
T2
T3
T4
T5
Leaves
Stem
Roots
Total

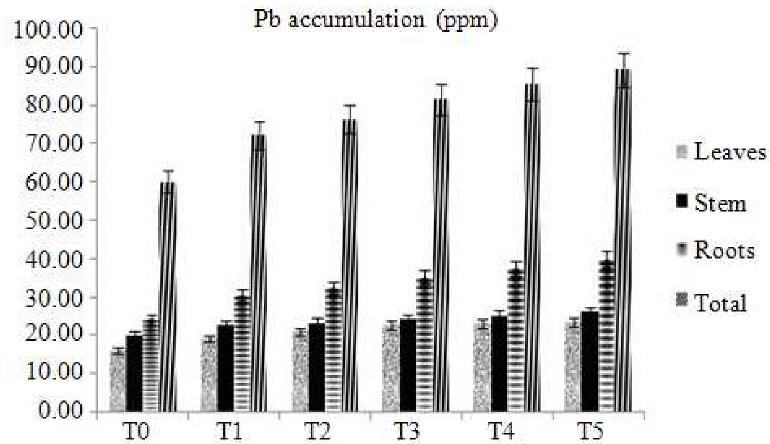
(b)


Zn accumulation (ppm)
250.00
200.00
150.00
100.00
50.00
0.00
T0
T1
T2
T3
T4
T5
Leaves
Stem
Roots
Total

(c)



(d)



(e)

Fig. 2. Accumulation of Cd (a), Fe (b), Zn (c) Cu (d) and Pb (e) concentrations in the plant parts after harvesting of *A.malaccensis* plant as influenced by different treatments. T0 = 100% soil, T1 = 80% soil + 20% sewage sludge, T2 = 60% soil + 40% sewage sludge, T3 = 40% soil + 60% sewage sludge, T4 = 20% soil + 80% sewage sludge, T5 = 100% sewage sludge

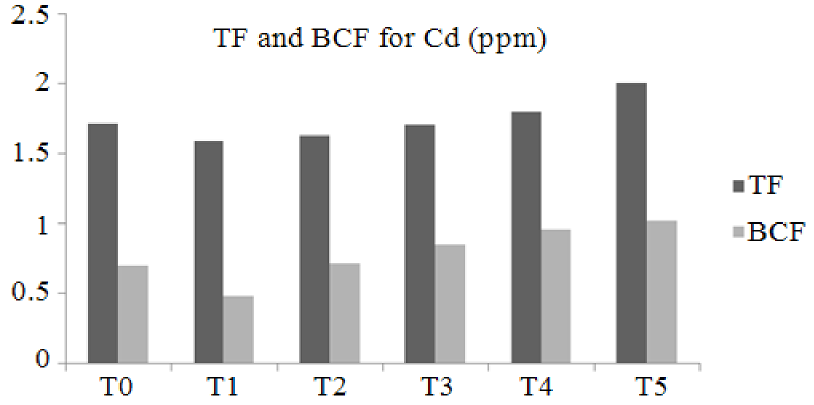
The results in **Table 3** showed not significantly different ($p \leq 0.05$) in the plant biomass between the treatments for all plant parts. T5 produced the highest biomass for roots (75.18), stem (70.00) and leaves (68.73), respectively. T0 produced the lowest biomass for roots (71.89), stem (63.65) and leaves (61.52), respectively.

3.3. Heavy Metal Concentrations in Growth Medium Before Planting and After Harvesting

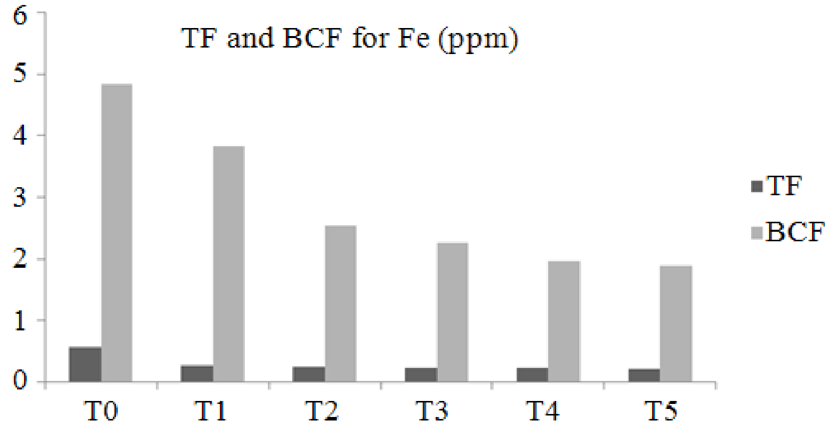
A.malaccensis was found to be able to remove high concentrations of heavy metals from the sewage sludge (Zn, Pb, Fe, Cd and Cu), especially in T5 where the planting media contained 100% sewage sludge. The Zn content of the sewage sludge was 287.44 ppm before planting in T5 and after harvesting, the Zn level decreased to 150.48 ppm (**Fig. 1a**).The highest decrease in Cd levels in the *A.malaccensis* growth media was observed in T5, where the level of Cd decreased by 2.5 ppm (**Fig. 1b**). The level of Fe in the T5 growth media decreased after harvesting (1473.8 ppm) compared to the initial Fe level of 2144.6 ppm (**Fig. 1c**). The highest decrease in Cu level in the *A.malaccensis* growth media was observed in T5, where the level of Cu decreased by 14.57 ppm (**Fig. 1d**). The level of Pb in the T5 growth media decreased after harvesting (77.80 ppm) compared to the initial Pb level (90.79 ppm), as shown in **Fig. 1e**.

3.4. Heavy Metal Concentration in Plant Parts

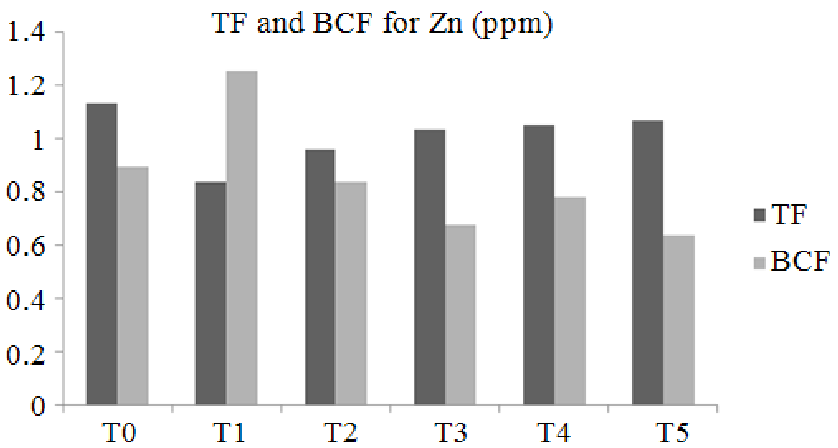
The highest Fe accumulation was observed in the roots of *A.malaccensis* in T5 (2770.75 ppm) (**Fig. 2**).


TF and BCF for Cd (ppm)
2.5
2
1.5
1
0.5
0
T0
T1
T2
T3
T4
T5
TF
BCF

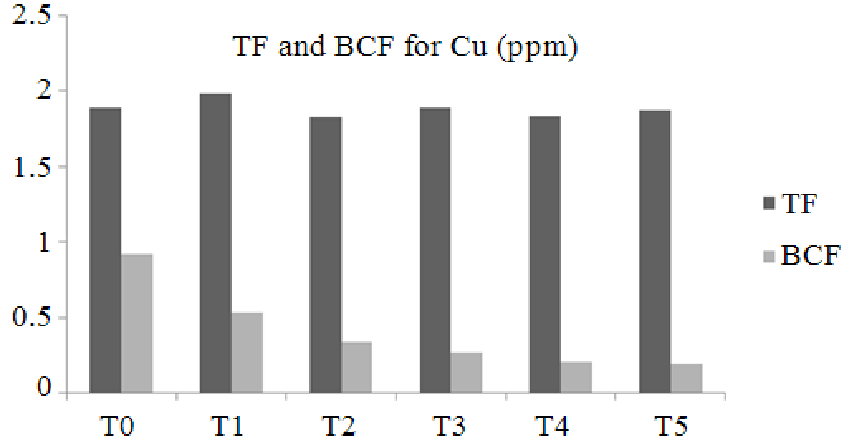
(a)


TF and BCF for Fe (ppm)
6
5
4
3
2
1
0
T0
T1
T2
T3
T4
T5
TF
BCF

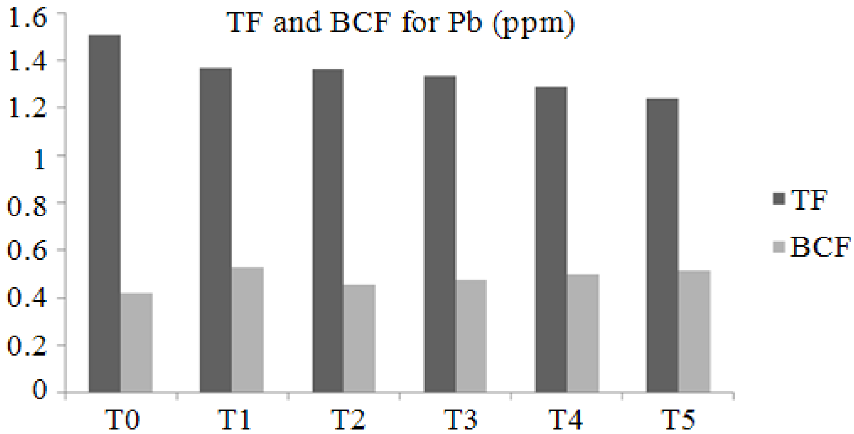
(b)


TF and BCF for Zn (ppm)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
T0
T1
T2
T3
T4
T5
TF
BCF

(c)



(d)



(e)

Fig. 3. Translocation factor and bioconcentration factor of Cd (a), Fe (b), Zn (c) Cu (d) and Pb (e) of *A.malaccensis* plant as influenced by different treatments. T0 = 100% soil, T1 = 80% soil + 20% sewage sludge, T2 = 60% soil + 40% sewage sludge, T3 = 40% soil + 60% sewage sludge, T4 = 20% soil + 80% sewage sludge, T5 = 100% sewage sludge

Furthermore, it was found that the leaves of the *A.malaccensis* absorbed higher levels of Fe compared to the stem. The stem of the *A.malaccensis* in T5 growth media accumulated the highest amount of Cd (3.75 ppm), while the lowest concentration was observed in the leaves in T0 (0.15 ppm). The highest Zn uptake was observed in the roots in the T5 growth media (95.62 ppm), while the lowest Zn uptake was noted in the leaves at the T0 growth media (8.74 ppm).

3.5. Translocation Factor (TF) and Bioconcentration Factor (BCF) of Heavy Metals

The TF for Fe was the lowest among all the other heavy metals. The lowest TF for Fe was recorded in T5 (0.20) and the highest was recorded in T0 (0.55), as shown in **Fig 3b**. Besides that, Fe recorded the highest BCF among the heavy metals. The highest BCF for Fe was recorded in T0 (4.82), followed by T1 (3.82). For Cu, the highest TF (1.98) was recorded in T1 (**Fig. 3d**), while the lowest BCF for Cu was recorded at T5 (0.18). The highest TF for Pb was recorded in T0 (1.51), while the lowest was in T5 (1.23) (**Fig. 3e**). The BCF for Pb was lowest in T0 and T2 treatments (0.42 and 0.45, respectively). The TF for Zn was prominent in T3, T4 and T5 (1.03, 1.04 and 1.06 respectively), as shown in **Fig 3c**. The highest BCF for Zn was observed in T1 (1.25), while the lowest BCF for Zn was recorded at T5 treatment

(0.64). **Fig 3a** showed that the highest TF for Cd was recorded in T5 (2.00), while the lowest BCF for Cd was recorded in T1 (0.48).

4. DISCUSSION

4.1. Changes in Chemical Properties of Growth Media

There was an increase in the pH of the growth media after harvest. The highest change in soil pH was recorded in T3 (5.13 to 5.32). The increase in pH was due to the uptake of acidic elements, such as Fe and other heavy metals, from the growth media by the *A.malaccensis* plant (Ghafoori *et al*., 2011). Furthermore, the application of sewage sludge in the growth media increased total carbon of each growth media. This indicates that sewage sludge has the ability to improve the overall organic matter content of the growth medium (Abdu *et al*., 2011), which in turn has the potential to improve the overall soil fertility (Rice, 2002). Therefore, sewage sludge has the potential to replace the usage of organic fertilizers, making it a viable, environment-friendly approach for the agriculture sector (Miranda, 2012). Besides that, soil organic matter improves the soil water holding capacity, making plants able to withstand short periods of droughts (Rice, 2002).

4.2. Growth Performance and Plant Biomass

The highest total height of the *A.malaccensis* plant (47.55cm) was recorded in the T5. *A.malaccensis* plant in the T5 growth media also produced the highest number of leaves (20) and the highest basal diameter (6.73cm). This shows that *A.malaccensis* exhibited the best growth in terms of height, number of leaves and basal diameter for the T5 growth media. Improvement in the growth parameters of *A.malaccensis* is due to the organic matter contribution by the sewage sludge (Majid *et al*., 2011; Parisa *et al*., 2010). Furthermore, these results indicate that the *A.malaccensis* plant has the ability to tolerate high levels of sewage sludge. T0 growth media exhibited the worst growth performance, indicating that a 100% soil growth media would be the least ideal growth media for the *A.malaccensis* plant, due to low organic matter content (Majid *et al*., 2011). After 16 weeks, T0 produced the lowest biomass of 63.65g and 61.52g for stem and leaves, respectively. T5 produced the highest biomass of 71.18g, 70.00g and 68.73g for roots, stem and leaves, respectively. Plant biomass plays an important role in the absorption of heavy metals from soil and water, making *A.malaccensis* an ideal phytoremediator (Majid *et al*., 2011). Plant used as a phytoremediator must have both high potential capacity to absorb elements from soil or water and large biomass (Parisa *et al*., 2010). T5 also produced the highest biomass, indicating that this plant can be used for remediation of sludge contaminated soils (Majid *et al*., 2011). Hence, results in T5 proved that *A.malaccensis* is suitable as a phytoremediator of sludge contaminated soils.

4.3. Heavy Metal Concentrations in Growth Medium

There was a decrease in the heavy metal concentrations (Cd, Fe, Zn, Cu and Pb) in all growth media after planting and harvesting of the *A.malaccensis* plant. The highest decrease for all the heavy metal levels (Cd, Fe, Zn, Cu and Pb) in the *A.malaccensis* growth medium was observed in T5. High metal concentrations in the growth media of plants would normally restrict germination and negatively affect the roots, shoots and leaf growth of the plants (Parisa *et al*., 2010). In this study, however, the *A.malaccensis* plant did not exhibit any of these traits, indicating it's tolerance to high concentrations of heavy metals, making it a prospective phytoremediator species (Purakayastha and Chhonkar, 2010).

4.4. Heavy Metal Concentration in Plant Parts

The highest total concentration of heavy metal (Fe, Zn, Cu, Cd and Pb) of the *A.malaccensis* plant was recorded in the T5 growth media. This is due to higher concentration of Fe, Zn, Cu, Cd and Pb present in the T5 growth media; hence, higher uptake of the heavy metals by the *A.malaccensis* plant. Although an increase in the accumulation of heavy metals would typically affect the growth performance of a plant negatively (Abdu *et al*., 2011), the *A.malaccensis* plant did not exihibit any inhibition to its growth parameters. This is a clear indication that the *A.malaccensis* plant is highly tolerant to heavy metals, making it a suitable phytoextractor (Majid *et al*., 2011; Parisa *et al*., 2010). The highest accumulation of Zn (95.62 ppm) was recorded in the roots of *A.malaccensis* in the T5 growth medium. Zn accumulation is higher in the roots compared to the leaves and roots in all treatments. This indicates that *A.malaccensis* is able to tolerate Zn toxicity (Fontes and Cox, 1998). The stem of the *A.malaccensis* in T5 recorded the highest Cd accumulation (3.75 ppm), followed by the roots of the *A.malaccensis* in T5 (2.55 ppm). This is because Cd is a mobile heavy metal, easily transported from the root of the plant to the stem (Gregor *et al*., 2004). The roots of the *A.malaccensis* were found to absorb significantly higher levels of Fe compared to other plant parts. The highest root accumulation of Fe was recorded in T5 (2770.75 ppm). The highest Pb in the roots was recorded in T5 (39.79 ppm), followed by T4 (37.29 ppm), while the lowest accumulation of Pb was noted in the leaves of T0 (16.08 ppm). The roots of the *A.malaccensis* in T5 had the highest uptake of Cu (8.51 ppm). The lowest Cu uptake was recorded in the stem of T0 (5.31 ppm). The stem had lower levels of Pb and Cu compared to those in the roots due to their low mobility (Gregor *et al*., 2004).

4.5. Comparison of Translocation Factor (TF) and Bioconcentration Factor (BCF) Among Treatments and Heavy Metals

The TF for Fe was the lowest among all other TF (0.20 in T5), while it's BCF was highest among all other BCF (4.82 in T0). This is due to the *A.malaccensis* plant able to store a large percentage of its Fe uptake in its roots (Yoon *et al*., 2006). Low TF and high BCF is a clear indication that the *A.malaccensis* plant is not an ideal phytoextractor for Fe, as ideal phytoremediator plants should store heavy metals in its stem. However, the TF for Cu was high (1.98 in T1), while its BCF was low (0.18 in T5). This was also true for Cd, where the TF for Cd was high (1.70 in T3), while its BCF was low (0.49 in T1). This indicates that the *A.malaccensis* plant could be a good phytoextractor of Cu and Cd (Majid *et al*., 2011; Parisa *et al*., 2010).

5. CONCLUSION

A.malaccensis plant was found to be able to tolerate heavy metals present in sewage sludge. The amount of heavy metal taken up by the *A.malaccensis* based on the translocation factor assessment was in the order:

$$Fe < Zn < Pb < Cu < Cd$$

A.malaccensis is a potential phytoextractor of Cd and Cu as it can store these heavy metals in its stem as well as effectively remove Zn from the soils on which it is planted. High amount of Fe, Zn and Pb was stored in the roots of the plant. Hence, *A.malaccensis* plant is not a suitable phytoremediator for Fe, Zn and Pb. The main use *A.malaccensis* is extraction of resin from its trunk. In practice, the trunk is harvested, but the roots containing Fe, Zn and Pb would remain in the soils.

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