UNIVERSITI PUTRA MALAYSIA

POTENTIAL OF TREATED SEWAGE SLUDGE AS ORGANIC FERTILIZER, AND PHYTOREMEDIATION CAPABILITY OF JARAK (Ricinus communis L.)

NUR AZIERA BINTI ZAINUDDIN

IPTPH 2018 2

POTENTIAL OF TREATED SEWAGE SLUDGE AS ORGANIC FERTILIZER, AND PHYTOREMEDIATION CAPABILITY OF JARAK (*Ricinus communis* L.)

By

NUR AZIERA BINTI ZAINUDDIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

December 2017

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment the requirement for the degree of Master of Science

POTENTIAL OF TREATED SEWAGE SLUDGE AS ORGANIC FERTILIZER, AND PHYTOREMEDIATION CAPABILITY OF JARAK (*Ricinus communis* L.)

By

NUR AZIERA BINTI ZAINUDDIN

December 2017

Chair: Professor Dato' Nik Muhamad Bin Nik Ab. Majid, PhD
Faculty: Institute of Tropical Forestry and Forest Products

Treated sewage sludge is generated from municipal wastewater. It has been stabilized by mechanical, biological and chemical treatments but heavy metal contents in this waste materials are still high. Improper disposal of treated sewage sludge can cause soil contamination and contributes to Environmental pollution. It can also affect human health and ecosystem. The objectives of this study are two-fold: The first objective is to determine whether treated sewage sludge can be used as an organic fertilizer. The second objective is to assess the potential of *Ricinus communis* as a phytoremediator of heavy metals in the sludge. For the greenhouse study, the experiment was laid out a Complete Randomized Design (CRD) with four replications. The growth medium was treated sewage sludge mixed with soil at five different levels mainly T1=100% soil (control), T2=25% treated sewage sludge+75% soil, T3= 50% treated sewage sludge+50% soil, T4= 75% treated sewage sludge + 25% soil and T5=100% treated sewage sludge. Soil samples before planting and at harvest were analyzed for texture, pH, N, P, K, C, and heavy metals (Cd, Cu, Fe, Mn, Pb and Zn) using standard procedures. Results showed that the amount of nutrients increased by increasing the amount of treated sewage sludge for both studies. In the greenhouse trial, there was a significant difference ($p \leq 0.05$) in N, P, K and C among plant parts. In the case of N, P and K the highest accumulation was in the leaves followed by stems and roots but for total C the highest was in the roots (41.2%) followed by stems and leaves (40.2% and 39.5%, respectively). The contents of Cd, Cu, Fe, Mn, Pb and Zn in the planting medium before planting were significantly ($p \leq 0.05$) different among the different levels of treated sewage sludge and different plant parts. In the field study the experiment was laid out in Complete Randomized Design (CRD) with three replications. The treatments evaluated were: T1= 0kg treated

sewage sludge, T2 = 100kg treated sewage sludge, T3 = 150kg treated sewage sludge and T4 = 200kg treated sewage sludge. The area for every plot was 18m^2 and the treated sewage sludge were spread and mixed with the soil. Soil pH, total N, P, K, C, and micronutrients (Cd, Cu, Fe, Mn, Pb and Zn) were analyzed using standard procedures. The result showed that application of treated sewage sludge significantly increased the percentage of total N, P, K and C in the soil. The availability of N, P, K and C supplied from treated sewage sludge has improved plant height and total biomass. The highest increment of plant height and total biomass were recorded in treatment T3 with the highest height of 3.18m and 1283.33g for total biomass. This study shows that treated sewage sludge contain high amounts of heavy metals particularly for Cd, Cu, Fe, Mn, Pb and Zn which can cause toxicity to our ecosystem but can be considered as a good source of plant nutrients. For both studies the values of bioconcentration factor (BCF) in all treatments for Cd, Fe, and Pb are less than one but for Cu, Mn and Zn the values are more than 1. This indicates that *Ricinus communis* is an efficient phtoremediator for Cu, Mn and Zn but not for Cd, Fe, and Pb. In the greenhouse and field studies Translocation factor (TF) of *Ricinus communis* in all treatments for all heavy metals (Cd, Cu, Fe, Mn, Pb and Zn) are more than one. Based on the BCF and TF values, *Ricinus communis* is an efficient phytoextractor for Cd, Cu, Fe, Mn, Pb and Zn. This species is also tolerant to high amount of treated sewage sludge and can grow well under this condition. It is recommended that future research should include evaluation of Environmental pollution especially on soil and water. In addition effect of using treated sewage sludge as an organic fertilizer on animal and human health need to be determined. This is because treated sewage sludge also contains heavy metals such as Cd, Cu, Fe, Mn, Pb and Zn which can be detrimental to human and animal health.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

POTENSI ENAP CEMAR KUMBAHAN TERAWAT SEBAGAI BAJA ORGANIK DAN JARAK *(Ricinus communis* L.) SEBAGAI PYTOREMEDIATOR UNTUK TANAH TERCEMAR

Oleh

NUR AZIERA BINTI ZAINUDDIN

Disember 2017

Pengerusi: Profesor Dato' Nik Muhamad Bin Nik Ab. Majid, PhD
Fakulti : Institut Perhutanan Tropika dan Produk Hutan

Enap cemar kumbahan terawat daripada air sisa perbandaran telah stabil dengan melalui beberapa rawatan namun kepekatan logam berat dalamnya masih tinggi. Pelupusan enap cemar kumbahan yang tidak sempurna boleh menyebabkan berlakunya pencemaran tanah dan menyumbang kepada masalah alam sekitar. Ia boleh menjejaskan kesihatan manusia dan ekosistem. Objektif pertama kajian ini adalah menentukan potensi enap cemar kumbahan dirawat sebagai baja organik dan objektif kedua adalah menilai potensi Jarak sebagai phytoremediator. Untuk kajian rumah hijau, eksperimen telah dijalankan menggunakan design (CRD) dengan empat replikasi. Medium pertumbuhan disediakan dengan mencampurkan enap cemar kumbahan dengan tanah pada lima tahap yang berbeza iaitu T1 = 100% tanah (kawalan), T2 = 25% enap cemar kumbahan dirawat + tanah 75%, T3 = 50% enap cemar kumbahan dirawat + 50% tanah, T4 = 75% enap cemar kumbahan + 25% tanah dan T5 = 100% enap cemar kumbahan. Pada akhir kajian ini, sampel tanah sebelum penanaman dan selepas penuaian dianalisis untuk tekstur tanah, pH, N, P, K, C, dan logam berat (Cd, Cu, Fe, Mn, Pb dan Zn) menggunakan prosedur piawai. Keputusan menunjukkan bahawa jumlah nutrien meningkat dengan peningkatan jumlah enap cemar kumbahan dirawat untuk kedua-dua kajian. Dalam percubaan rumah hijau, terdapat perbezaan yang signifikan ($p \leq 0.05$) dalam N, P, K dan C di kalangan bahagian tumbuhan. Dalam kes N, P dan K, pengumpulan tertinggi berada di daun yang diikuti oleh batang dan akar tetapi jumlah C tertinggi adalah pada akar (41.2%) diikuti oleh batang dan daun (40.2% dan 39.5%). Kandungan Cd, Cu, Fe, Mn, Pb dan Zn dalam medium penanaman sebelum penanaman ($p \leq 0.05$) berbeza di antara tahap enap cemar kumbahan dirawat mengikut bahagian tumbuhan yang berlainan. Dalam kajian lapangan,

eksperimen telah dijalankan dalam bentuk (CRD) dengan tiga replikasi. Rawatan yang dinilai ialah: T1 = 0kg enap cemar kumbahan, T2 = 100kg enap cemar kumbahan, T3 = enap cemar kumbahan 150kg dan T4 = 200kg enap cemar kumbahan. Keluasan kawasan untuk setiap plot ialah 18m^2. Sisa enap cemar kumbahan dirawat dicampur dengan tanah. pH tanah, jumlah N, P, K, C, dan mikronutrien (Cd, Cu, Fe, Mn, Pb dan Zn) dianalisis menggunakan prosedur piawai. Keputusan menunjukkan bahawa penggunaan enapc emar kumbahan dirawat meningkatkan peratusan jumlah N, P, K dan C di dalam tanah dengan ketara. Ketersediaan N, P, K dan C yang dibekalkan daripada enap cemar kumbahan dirawat telah meningkatkan ketinggian tumbuhan dan jumlah biomass. Peningkatan tertinggi ketinggian tumbuhan dan jumlah biomass direkodkan dalam rawatan T3 dengan ketinggian tertinggi 3.18m dan 1283.33g bagi jumlah biomass. Kajian ini menunjukkan bahawa enap cemar kumbahan dirawat boleh digunakan sebagai baja organik. Untuk kedua-dua kajian nilai-nilai faktor biocontent (BCF) dalam semua rawatan untuk Cd, Fe, dan Pb adalah kurang daripada satu tetapi untuk Cu, Mn dan Zn nilainya lebih dari 1. Ini menunjukkan bahawa *Ricinus communis* adalah phytoremediator yang efisien untuk Cu , Mn dan Zn tetapi bukan untuk Cd, Fe, dan Pb. Dalam kajian rumah hijau dan lapangan, Translocation factor (TF) *Ricinus communis* dalam semua rawatan untuk semua logam berat (Cd, Cu, Fe, Mn, Pb dan Zn) lebih daripada satu. Berdasarkan nilai BCF dan TF, *Ricinus communis* adalah phytoextractor yang cekap untuk Cd, Cu, Fe, Mn, Pb dan Zn. Spesies ini juga mampu hidup di kawasan yang mempunyai kandunagn enapcemar kumbahan terawat yang tinggi dan boleh berkembang dengan baik di bawah keadaan ini. Adalah disyorkan untuk penyelidikan masa hadapan perlu dimasukkan juga penilaian pencemaran alam sekitar terutama pada tanah dan air. Di samping itu kesan penggunaan enap cemar kumbahan dirawat sebagai baja organik pada haiwan dan kesihatan manusia perlu ditentukan. Ini kerana enap cemar kumbahan dirawat juga mengandungi logam berat seperti Cd, Cu, Fe, Mn, Pb dan Zn yang boleh menjejaskan kesihatan manusia dan haiwan apabila memasuki rantaian makanan.

ACKNOWLEDGEMENTS

ALHAMDULILLAH, my gratitude goes to Allah s.w.t who gave me patience, wisdom, determination and opportunity to complete this study.

I would like to express my sincere appreciation and respect to my supervisor, Professor Dato' Dr. Nik Muhamad Bin Nik Ab Majid for his guidance, advice and his confidence in me. I cannot thank him enough for his support and without his supervision; this study would not have been possible. I am also grateful to my supervisory committee members Assoc. Prof. Dr. Mohd Nazre Saleh and Dr. Normala Halimoon for their time and advice during this research.

I am deeply indebted to my husband Mohd Syafiq Nizomuddin Bin Mat Saad and my sons Muhammad Fitri and Muhammad Firash, for their love, support and patience. I am also very grateful to my father, Zainuddin Bin Dali and mother, Arbayah Binti Asor, for their continuous support throughout my many years of education. I have no suitable words that can fully describe their everlasting love to me. I hope the accomplishment of this study represents a small token of my appreciation. I also like to thank my dear brother, Izzat for his support. I also would like to thank both my in-laws Mat Saad Bin Mat Desa and Kharani Binti Rabarie for their encouragement.

Thanks are also extended to Ms. Zarina Abdul Rahman, Dr. Md Moniral Islam, Mr. Zahir Abdul Hamid, and Mr Nik Mohd. Shibli Nik Jaafar, Miss Aiza Shaliha Binti Jamaludin, Miss Dian Rahmi Zulkarnaini and Miss Fairuz Mohd Sani for their kindness and invaluable help throughout this study.

Last but not least, I acknowledge the Ministry of Higher Education Malaysia for financial support to conduct this project through the Research University Grant Scheme (91784) to Universiti Putra Malaysia. I also thank to Indah Water Konsortium (IWK) Kuala Sawah Negeri Sembilan, Malaysia for providing the treated sewage sludge used in this research.

I certify that a Thesis Examination Committee has met on 22 December 2017 to conduct the final examination of Nur Aziera binti Zainuddin on her thesis entitled "Potential of Treated Sewage Sludge as Organic Fertilizer, and Phytoremediation Capability of Jarak (*Ricinus communis* L.)" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Mohamad Azani bin Alias, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Osumanu Haruna Ahmed, PhD
Professor
Faculty of Agriculture and Food Science (Bintulu Campus)
Universiti Putra Malaysia
(Internal Examiner)

Zulkifli Yusop, PhD
Professor
Universiti Teknologi Malaysia
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 27 February 2018

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of requirement for degree of Master of Science. The members of Supervisory Committee were as follows:

Nik Muhamad Nik Ab. Majid, PhD
Professor
Institute of Tropical Forestry and Forest Products
Universiti Putra Malaysia
(Chairman)

Mohd. Nazre Saleh, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Normala Halimoon, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotation, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for other degree at any other institution;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings popular writings, seminars papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____Date: _____

Name and Metric No.: Nur Aziera Binti Zainuddin (GS24848)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of the thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature _____
Name of Chairman of Supervisory Committee Prof. Dato' Dr. Nik Muhamad Nik Ab. Majid

Signature _____
Name of Member of Supervisory Committee Assoc. Prof. Dr. Mohd. Nazre Saleh

Signature _____
Name of Member of Supervisory Committee Dr. Normala Halimoon

TABLE OF CONTENTS

		Page
ABSTRACT		i
ABSTRAK		iii
ACKNOWLEDGEMENTS		v
APPROVAL		vi
DECLARATION		viii
LIST OF TABLES		xiii
LIST OF FIGURES		xiv
LIST OF ABBREVIATIONS		xv
CHAPTER		
1	**INTRODUCTION**	1
2	**LITERATURE REVIEW**	
	2.1 Introduction	4
	2.2 Organic waste	4
	2.3 Sewage sludge production in Malaysia	4
	2.4 Wastewater treatment and sewage sludge production	6
	2.5 Chemical properties of sewage sludge	7
	2.6 Heavy metal contamination	8
	2.6.1 Heavy metal accumulation in the soil	8
	2.6.2 Heavy metal bioaccumulation in food chain	9
	2.7 Intensive agriculture farming system	9
	2.8 Mineral fertilizer consumption in Malaysia	9
	2.9 Negative effects of excessive use of mineral fertilizers	10
	2.10 Biological agriculture	10
	2.11 Phytoremediation	11
	2.11.1 Types of phytoremediation	11
	(i)Phytoextraction	12
	(ii)Phytodegradation	12
	(iii)Phytovolatilization	12
	(iv)Rhizofiltration	12
	(v)Phytostabilization	13
	2.12 Hyperaccumulators	13
	2.13 Indicators of phytoremediaton potential	13
	2.14 Plant response to heavy metals	14
	2.15 *Ricinus communis*	14
	(i) Botanical classification	14
	(ii) Growth characteristics	14
	(iii)Uses of *Ricinus communis*	16

3 MATERIALS AND METHODS

3.1	Location of the study	19
3.2	Greenhouse experiment	19
3.3	Field experiment	21
3.4	Measurement of parameters	22
3.5	Laboratory Analysis	23
3.6	Statistical Analysis	23
3.7	Accumulation and Translocation of Metals in Plants	23

4 RESULTS AND DISCUSSION

4.1	Introduction	25
	I. SEWAGE SLUDGE AS AN ORGANIC FERTILIZER	
4.2	Soil texture	26
4.3	Soil pH	26
4.4	N, P, K and total C in the growth medium before planting and at harvest for greenhouse and field studies	28
4.5	N, P, K and total C in plant parts for the greenhouse and field studies	30
4.6	Plant height	32
4.7	Total biomass	33
4.8	Heavy metal content in the sewage sludge	34
	II. PHYTOREMEDIATION POTENTIAL OF JARAK (*Ricinus communis*)	
4.9	Heavy metals in growth medium	
	a. Cd	35
	b. Cu	36
	c. Fe	37
	d. Mn	38
	e. Pb	39
	f. Zn	40
4.10	Heavy metals contents in plant tissues	
	a. Cd	42
	b. Cu	43
	c. Fe	44
	d. Mn	46
	e. Pb	47
	f. Zn	48
4.11	Heavy metals accumulation and translocation in plants	
	a. Biocontent Factor	50
	b. Translocation Factor	51

5 SUMMARY, GENERAL CONCLUSION AND RECOMMENDATIONS 53

REFERENCES 55
APPENDICES 65
BIODATA OF STUDENT 86
LIST OF PUBLICATIONS 87

LIST OF TABLES

Table		Page
3.1	Treatments in the greenhouse study	19
3.2	Greenhouse study layout	20
3.3	Treatments in the field study	21
3.4	Field study layout	21
4.1	Soil Texture (green house study)	26
4.2	Soil Texture (field study)	26
4.3	pH of growth medium (greenhouse study)	27
4.4	pH of growth medium (field study)	27
4.5	N, P, K and total C in the growth medium before planting and at harvest (greenhouse study)	29
4.6	N, P, K and total C in the growth medium before planting and at harvest (field)	29
4.7	N, P, K and total carbon in the plant parts (greenhouse study)	31
4.8	N, P, K and total carbon in the plant parts (field study)	31
4.9	Total Cd in the growth medium (greenhouse study)	36
4.10	Total Cd in the growth medium (field study)	36
4.11	Total Cu in the growth medium (greenhouse study)	37
4.12	Total Cu in the growth medium (field study)	37
4.13	Total Fe in the growth medium (greenhouse study)	38
4.14	Total Fe in the growth medium (field study)	38
4.15	Total Mn in the growth medium (greenhouse study)	39
4.16	Total Mn in the growth medium (field study)	39
4.17	Total Pb in the growth medium (greenhouse study)	40
4.18	Total Pb in the growth medium (field study)	40
4.19	Total Zn in the growth medium (greenhouse study)	41
4.20	Total Zn in the growth medium (field study)	41

LIST OF FIGURES

Figure		Page
2.1	*Ricinus communis* tree	15
2.2	*Ricinus communis* leaves	15
2.3	*Ricinus communis* fruits	15
2.4	*Ricinus communis* seeds	15
3.1	Seedlings in the greenhouse study	20
3.2	Seedlings in the field study	22
4.1	Plant height by treatments (greenhouse study)	32
4.2	Plant height by treatments (field study)	33
4.3	Total biomass by treatments (greenhouse study)	34
4.4	Total biomass by treatments (field study)	34
4.5	Cd content in different plant parts (greenhouse study)	42
4.6	Cd content in different plant parts (field study)	43
4.7	Cu content in different plant parts (greenhouse study)	44
4.8	Cu content in different plant parts (field study)	44
4.9	Fe content in different plant parts (greenhouse study)	45
4.10	Fe content in different plant parts (field study)	45
4.11	Mn content in different plant parts (greenhouse study)	46
4.12	Mn content in different plant parts (field study)	47
4.13	Pb content in different plant parts (greenhouse study)	48
4.14	Pb content in different plant parts (field study)	48
4.15	Zn content in different plant parts (greenhouse study)	49
4.16	Zn content in different plant parts (field study)	49
4.17	Biocontent factor (greenhouse study)	50
4.18	Biocontent factor (field study)	51
4.19	Translocation factor (greenhouse study)	52
4.20	Translocation factor (field study)	52

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of Variance
BCF	Biocontent factor
CEC	Cation exchange capacity
CRD	Complete Randomized Design
H_2O_2	Hydrogen peroxide
HNO_3	Nitric acid
kg	Kilogram
IWK	Indah Water Konsortium
m^2	Meter square
m	Metre
mg	miligram
Pb $(NO_3)^2$	Pb (II) nitrate
mg kg^{-1}	parts per million
rpm	Revolutions per minute
Sec	Second
TF	Translocation factor
USDA	United States Department of Agriculture

CHAPTER 1

INTRODUCTION

The ever increasing sewage sludge production in Malaysia has become a major challenge in terms of logistic in disposal and Environmental problems. The current production of sewage sludge in Malaysia is approximately five million m^3 per year and this is expected to increase to seven million m^3 by 2022 (IWK, 2011). IWK is facing problems in disposing this waste due to the strict national Environmental policy and limited disposal sites.

The cost to manage sewage sludge disposal is approximately RM 1 billion per year (Kadir and Mohd, 1998). Treated sewage sludge is currently disposed at landfill sites but this method is not Environmental friendly due to the high content of heavy metals. It will also cause heavy metal toxicity in our Environment and will adversely affect public health. Heavy metals may enter human food chain and accumulated in the human body.

One of the most economic and safe methods to dispose sewage sludge is by converting it to organic fertilizer. Sewage sludge contains high amounts of essential nutrients for plant growth and development. For Malaysia to achieve food security, agriculture production needs to be increased through the use of organic fertilizers from unwanted wastes such as sewage sludge. According to the Department of Statistics Malaysia, about 3.95 million tons of mineral fertilizers were imported into Malaysia in 2009 with incurred cost of about RM 4.02 billion (US$0.94 billion) and increased to 5.45million tons in 2013. As a result, the consumer price index (CPI) for food has increasing with the increasing cost of fertilizer for crop production. Latest consumer price index for food in April 2014 released by the Department of Statistics Malaysia showed an increase of 3.6% compared with that of April 2013. Furthermore, continuous and excessive use of mineral fertilizers in agriculture will cause soil degradation and Environmental pollution by heavy metals, eutrophication, and greenhouse gas emissions (Savci, 2012).

The concept of biological agriculture has been practiced in many countries. According to the Federation of Organic Agriculture Movement “Biological agriculture is an ecologically, socially, and economically sustainable agricultural production system which combines traditional, innovation and science to sustain and enhance soil health and fertility, maximizing yield and production and at the same time minimizing the negative effects on Environment and human health. This will promote a sustainable practice and a better quality of life for the entire ecosystem” (IFOAM, 2014). In essence the combined use of organic fertilizers produced from organic waste such as treated sewage sludge with mineral fertilizers is recommended for

agricultural production. This has been successfully practiced in some developed countries but similar approach is yet to be implemented in Malaysia.

Besides having high amount of essential plant nutrients, treated sewage sludge also contains heavy metals which can affect human health and Environment. Soil polluted by heavy metals can be remediated by physical, chemical or biological techniques. The conventional remediation methods such as physical, thermal and chemical treatments are not only expensive but also economically and environmentally unsustainable. Therefore, there is a need to develop an effective biological soil remediation technique to remove heavy metals without degrading soil health. Phytoremediation can be an alternative method to treat sewage sludge after disposal at the landfill.

Phytoremediation can remove or stabilize heavy metals in the soil. This method is the most economical way to remediate polluted area. It is be classified into six types mainly phytoextraction, phytotransformation, phytostabilization, phytovolatilization, rhizodegradation and rhizofiltration. Phytoextraction is a process when the plant absorbs and translocates contaminants from soil to above ground parts (Chhotu and Fulekar, 2009). Plants which are classified as hyper-accumulator have the capability to accumulate heavy metals more than 100 times than the non-accumulators (Chaney *et al*., 1997).

For a hyper-accumulator plant, the distribution of heavy metals is high in the shoot compared to the root and stem. In order to be classified as a hyper-accumulator, the plant must be tolerant to high levels of heavy metals, able to accumulate high contents of heavy metals in the aboveground portion, rapid growth rate and produces high biomass (Reeves and Baker, 2000) . The most important soil chemical property that influences heavy metal uptake by plant is soil pH. The greatest uptake of heavy metals is between pH 5.5 to 6.5. Heavy metals distribution in plant parts depends on the type of heavy metals. Most of the heavy metals are concentrated in the root tissues compared to the leaf or stem especially for Pb, Ni and Cu.

In order to promote biological agriculture and sustainable management of treated sewage sludge in Malaysia, this research was conducted to determine whether treated sewage sludge can be used as an organic fertilizer. The second objective is to assess the potential of *Ricinus communis* as a phytoremediator. *This species* was selected because of its hardiness and commonly found growing on contaminated soils. This research involved both the greenhouse and field trials and was conducted in Universiti Putra Malaysia campus.

This thesis has been organized in five chapters. Chapters 1, 2, and 3 are the introduction, literature review, and methodology, respectively. Chapter 4 discussed the potential of sewage sludge as an organic fertilizer and also addressed the phytoremediation capability of *Ricinus communis*. The summary, conclusion and recommendations from this study were described in Chapter 5.

REFERENCES

Adams, T.M., and Sanders, J.R. 1984. The effects of pH on the release to solution of Zn, Cu and nickel from metal-loaded sewage sludge. *Environmental Pollution Series B, Chemical and Physical* 8(2):85-99.

Adediran, J.A., Taiwo, L.B., Akande, M.O., Sobulo, R.A., and Idowu, O.J. 2005. Application of organic and inorganic fertilizer for sustainable maize and cowpea yields in Nigeria. *Journal of plant nutrition* 27(7):1163-1181.

Ahmad, A.L., Sumathi, S., and Hameed, B.H. 2006. Coagulation of residue oil and suspended solid in palm oil mill effluent by chitosan, alum and PAC. *Chem. Eng. J.* (118):99-105.

Akdeniz, H., Yilmaz, I., Bozkurt, M.A. and Keskin, B., 2006. The Effects of Sewage Sludge and Nitrogen Applications on Grain Sorghum Grown (*Sorghum vulgare L.*) in Van-Turkey. *Polish journal of Environmental studies* 63 : 895-901.

Arcak, S., A. Karaca, E. Erdogan, and C. Türkmen. 2000. A study on potential agricultural use of sewage sludge of Ankara wastewater treatment plant, p. 345-349. *In* Proceedings of the International Symposium on Desertification, 13 to 17 June 2000, Konya, Turkey. The Soil Science Society of Turkey, Ankara, Turkey.

Baker, A.J.M. 1981. Accumulators and excluders strategies in the response of plants to heavy metals," *Journal of Plant Nutrition* 3: 643–654.

Baker, A.J.M., and Brooks, R.R. 1989. Terrestrial higher plants which hyperaccumulate metallic. *Journal of Bio-recovery*1:81-126.

Baker, A.J.M., McGrath, S.P., Reeves, R.D. and Smith, J.A.C., 2000. Metal Hyperaccumulator Plants: A Review of the Ecology and Physiology of a Biological Resource for Phytoremediation of Metal-Polluted Soils. In: Terry, N. and Banuelos, G., Eds., Phytoremediation of Contaminated Soil and Water, Lewis Publishers, London 85-107.

Barzegar, A.R., Yousefi, A. and Daryashenas, A. 2002. The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. Plant and soil 247(2):295-301.

Bauddh, K. and Singh, R.P. 2012. Growth, tolerance efficiency and phytoremediation potential of Ricinus communis (L.) and Brassica juncea (L.) in salinity and drought affected Cd contaminated soil. *Ecotoxicology and Environmental safety* 85:13-22.

Berti, W.R. and Cunningham, S.D. 2000. Phytostabilization of metals. Phytoremediation of toxic metals: using plants to clean-up the Environment. *New York, John Wiley & Sons, Inc.*71-88.

Bhargava, A., Carmona, F.F., Bhargava, M. and Srivastava, S. 2012. Approaches for enhanced phytoextraction of heavy metals. *Journal of Environmental Management* 105:103-120.

Bot, A. and Benites, J. 2005. The importance of soil organic matter: key to drought-resistant soil and sustained food production (No. 80). *Food & Agriculture Org.*

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* 54(5):464-465.

Bowen, H. J. M. 1979.Environmental Chemistry of the Elements, Academic Press, New York, 333

Bright, D.A., and Healey, N. 2003. Contaminant risks from biosolids land application: contemporary organic contaminant levels in digested sewage sludge from five treatment plants in Greater Vancouver, British Columbia. *Environmental Pollution* 126(1):39-49.

Brooks, R.R., Chambers, M.F., Nicks, L.J., and Robinson, B.H. 1998: Phytomining. Trends in Plant and Science. 1: 359-362.

Broyer, T.C., Johnson, C.M. and Paull, R.E., 1972. Some aspects of Pb in plant nutrition. *Plant and Soil* 36(1):301-313.

Carbonell, G., Pro, J., Gómez, N., Babín, M.M., Fernández, C., Alonso, E., Tarazona, J.V. 2009. Sewage sludge applied to agricultural soil: ecotoxicological effects on representative soil organisms. *Ecotox. EnvFe. Safe.* 72 (4):1309–1319.

Chandra, P. and Kulshreshtha, K., 2004. Chromium accumulation and toxicity in aquatic vascular plants. *The Botanical Review* 70(3):313-327.

Chaney, R. L., Malik, M., Y. M. Li. 1997. “Phytoremediation of soil metals,” *Current Opinion in Biotechnology* 8: 279–284.

Chibuike, G.U., and Obiora, S.C. 2014. Heavy metal polluted soils: effect on plants and bioremediation methods. *Applied and Environmental Soil Science*.

Chhotu D.J., and Fulekar M.H. 2009. Phytoremediation of heavy metals: Recent techniques. African J.of Biotechnology Vol 8(6) pp 921-92

Cui, S., Zhou, Q. and Chao, L., 2007. Potential hyperaccumulation of Pb, Zn, Cu and Cd in endurant plants distributed in an old smeltery, northeast China. *Environmental Geology* 51(6):1043-1048.

Dowdy, R.H., Larson, W.E., Titrud, J.M. and Latterell, J.J. 1978. Growth and metal uptake of snap beans grown on sewage sludge-amended soil: a four-year field study. *Journal of Environmental Quality* 7(2):252-257.

Drown, D.C., Harper, K. and Frame, E. 2001. Screening vegetable oil alcohol esters as fuel lubricity enhancers. *Journal of the American Oil Chemists' Society* 78(6):579-584.

EC DG ENV. 2001. Working Document on Biowaste, 2nd Draft. EC DG ENV.A.2/LM, Brussels, EC Web site Europa: http://europa.eu.int/comm/Environment/waste/facts_en.htm.

Epstein E. 1997. The Science of Composting, Technomic Publishing Co Inc.

Epstein E. 2003. Land Application of Sewage Sludge and Biosolids. Lewis, Boca Raton, Florida.

Food and Agriculture Organization of the United Nations, Rome, 2004.

Gana, A. K.; Yusuf, A. F. and Apuyor, B. 2013. Castor Oil Plant and its Potential in Transformation and Industrialization of Under Developing Nations in the World. *Advanced Journal of Agricultural Research* 1(005): 072-079.

Ghosh, M. and Singh, S., 2005. A review on phytoremediation of heavy metals and utilization of it's by products. *Asian J Energy EnvFe* 6(4):18.

Green, S. R., Vogeler, I., Clothier, B.E., Mills, T.M. and Dijssel, C. van den. 2003. Modeling water uptake by mature apple tree. *Aus. J. of Soil Research* 41:365-380.

Grytsyuk, N., Arapis, G., Perepelyatnikova, L., Ivanova, T. and Vynograds' ka, V. 2006. Heavy metals effects on forage crops yields and estimation of elements accumulation in plants as affected by soil. *Science of the Total Environment* 354(2):224-231.

Huang, H., Yu, N., Wang, L., Gupta, D.K., He, Z., Wang, K., Zhu, Z., Yan, X., Li, T. and Yang, X.E. 2011. The phytoremediation potential of bioenergy crop *Ricinus communis* for DDTs and Cd co-contaminated soil. *Bioresource technology* 102(23):11034-11038.

IFOAM (International Federation of Organic Agriculture Movements). 2014. Organic International.

Igwe, J.C. and Abia, A.A. 2006. Sorption kinetics and intrapaticulate diffusivity of As (III) bioremediation from aqueous solution, using modified and unmodified coconut fiber. *Ecletica Quimica* 31(3):23-29.

IWK(Indah Water Konsortium) annual report. 2011. Making a difference to our life and Environment.

Jabeen, R., Ahmad, A. and Iqbal, M. 2009. Phytoremediation of heavy metals: physiological and molecular mechanisms. *The Botanical Review* 75(4):339-364.

Jan, A.T., Azam, M., Siddiqui, K., Ali, A., Choi, I. and Haq, Q.M.R. 2015. Heavy metals and human health: Mechanistic insight into toxicity and counter defense system of antioxidants. *International journal of molecular sciences* 16(12): 29592-29630.

Kabata-Pendias, A. and Pendias, H. 1992. Trace metals in soils and plants. CRC Press, Boca Raton, Fla, USA.

Kadir, M. A., & Mohd, H. D. (1998). The Management of Municipal Wastewater Sludge in Malaysia. *Tropics* 28:109-120.

Khan, S.A., Mulvaney, R.L., Ellsworth, T.R. and Boast, C.W., 2007. The myth of nitrogen fertilization for soil carbon sequestration. *Journal of Environmental Quality* 36(6):1821-1832.

Kumpiene, J., Lagerkvist, A. and Maurice, C., 2008. Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments–a review. Waste management 28(1):215-225.

Ladislas, S., El-Mufleh, A., Gérente, C., Chazarenc, F., Andrès, Y. and Béchet, B. 2012. Potential of aquatic macrophytes as bioindicators of heavy metal pollution in urban stormwater runoff. *Water, Air, & Soil Pollution* 223(2):877-888.

Liu, J.Y. and Sun, S.Y. 2013. Total contents and different fractions of heavy metals in sewage sludge from Guangzhou, China. Transactions of Nonferrous Metals Society of China 23(8):2397-2407.

Madejon, P., Murillo, J.M., Maranon, T., Cabrera, F. and López, R. 2002. Bioaccumulation of As, Cd, Cu, Fe and Pb in wild grasses affected by the Aznalcóllar mine spill (SW Spain). *Science of the Total Environment* 290(1) :105-120.

Maira. M. and Marcia B de M. N. 2013. Castor Breeding, Plant Breeding from Laboratories to Fields, Prof. Sven Bode Andersen (Ed.), InTech, DOI: 10.5772/56216. Available from: https://www.intechopen.com/books/plant-breeding-from-laboratories-to-fields/castor-breeding

Majid, N.M., Islam, M.M., Abdul Rauf, R., Ahmadpour, P. and Abdu, A., 2012. Assessment of heavy metal uptake and translocation in Dyera costulata for phytoremediation of Cd contaminated soil. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science* 62(3):245-250.

Maryam, G., Majid, N.M., Islam, M., Ahmed, O.H., & Abdu, A. (2015). Phytoremediation of Cu-contaminated sewage sludge by tropical plants. Journal of Tropical Forest Science. 27:535-547.

McGarey, W.A. 1993. The Oil That Heals: A Physician's Success with Castor Oil Treatments. ARE Press.

McGrath, S.P. and Zhao, F.J. 2003. Phytoextraction of metals and metalloids from contaminated soils. *Current Opinion in Biotechnology* 14(3):277-282.

McLaughlin, M.J. and Smolders, E. 2001. Background Zn contents in soil affect the Zn sensitivity of soil microbial processes - A rationale for a metalloregion approach to risk assessments. *Environmental Toxicology and Chemistry* 20(11), :2639-2643.

Meagher, R.B. 2000. Phytoremediation of toxic elemental and organic pollutants. *Current opinion in plant biology* 3(2):153-162.

Mengel, K., Kirkby, E.A., Kosegarten, H., and Appel, T. 2001. Principles of Plant Nutrition, 5th ed. Dordrecht: Kluwer Academic Publisher.

Merillot, J. M. 1998. Management strategies related to legislature, economics, agronomic and Environmental impact of organic waste.pp:15-24. In: Martines, J and Maudet, M(Ed), Proceedings of the 8th International Conference on Management Strategies for Organic Waste use in Agriculture, 26-29 May, Cemagref, France.

Morera, M.T. Echeverria, J. Garrido, J. 2002. Bioavailability of heavy metals in soils amended with sewage sludge. Can. J. of Soil Sci. 82 (4), 433-438.

Moreira, C. S., Casagrande, J. C., Alleoni, L. R. F., De Camargo, O. A., & Berton, R. S. 2008. Nickel adsorption in two Oxisols and an Alfisol as affected by pH, nature of the electrolyte, and ionic strength of soil solution. *Journal of Soils and Sediments 8*(6): 442–451.

Mulligan, C.N., Yong, R.N. and Gibbs, B.F. 2001. Remediation technologies for metal-contaminated soils and groundwater: an evaluation. *Engineering geology* 60(1), :193-207.

O'Connor, G.A., Sarkar, D. Brinton, S.R., Elliot, H.A and Martin, F.G. 2004 *Phytoavailability of biosolids phosphorus. J. Env. Qual* 33: 703-712.

Ogunniyi, D.S. 2006. Castor oil: a vital industrial raw material. *Bioresource technology* 97(9):1086-1091.

Omran, M.S., Waly, T.M., Elnaim, E.A. and El Nashar, B.M.B. 1988. Effect of sewage irrigation on yield, tree components and heavy metals accumulation in navel orange trees. *Biological Wastes* 23(1):17-24.

Padmavathiamma, P.K. and Li, L.Y. 2007. Phytoremediation technology: hyper-accumulation metals in plants. *Water, Air, and Soil Pollution* 184(1-4):105-126.

Pagliai, M., Guidi, G., La Marca, M., Giachetti, M. and Lucamante, G. 1981. Effects of sewage sludges and composts on soil porosity and aggregation. *Journal of Environmental Quality* 10(4):556-561.

Pompeu, R.C.F.F. 2009. Substituicao do farelo de soja pela torta de mamona destoxificada em dietaspara ovinos: Valor nutritivo e desempenho bioeconomico. Ph.D. diss. Univ. Federal do Ceara, Fortaleza. (In Portu- guese, with English abstract.).

Rajkumar, M. and Freitas, H. 2008. Influence of metal resistant-plant growth-promoting bacteria on the growth of Ricinus communis in soil contaminated with heavy metals. *Chemosphere* 71(5): 834-842.

Ramachandra, T.V. 2006. Soil and groundwater pollution from agricultural activities. The Energy and Resources Institute (TERI).

Ramirez Zamora R.M., Orta de Velasquez M.T., Duran Moreno A., and Malpica de la Torre J. 2002. Characterization and conditioning of Fenton sludge issued from wastewater treatment. *J. Water Sci. Tech* 46(10):43-9.

Raskin, I., Kumar, P.N., Dushenkov, S. and Salt, D.E. 1994. Biocontent of heavy metals by plants. *Current Opinion in biotechnology* 5(3):285-290.

Raskin, I., Smith, R.D. and Salt, D.E. 1997. Phytoremediation of metals: using plants to remove pollutants from the Environment. *Current opinion in biotechnology* 8(2):221-226.

Raskin, I. and Ensley, B.D. 2000. Phytoremediation of toxic metals. John Wiley and Sons.

Raun, W.R., Johnson, G.V., Solie, J.B., Stone, M.L. and Freeman, K. 2007. Use of within-field-element-size CV for improved nutrient fertilization in crop production. U.S. Patent 7,188,450.

Reed, S.T., Allen, M.G., Martens, D.C. and McKenna, J.R. 1993. Cu fractions extracted by mehlich-3 from soils amended with either CuSO4 or Cu rich pig manure. *Communications in Soil Science & Plant Analysis* 24(9-10):827-839.

Reeves, R.D. and A.J.M. Baker, 2000. Metal-Accumulating Plants. In: Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment, Raskin, I. and B.D. Ensley (Eds.). Chapter 12, John and Wiley and Sons, Inc., New York, USA., ISBN-13: 9780471192541, pp: 193-229.

Reichman, S.M. 2002. The Responses of Plants to Metal Toxicity: A Review Forusing on Cu, Mn & Zn. Melbourne: Australian Minerals & Energy Environment Foundation pp. 22-26.

Robinson, B.H., Lombi, E., Zhao, F.J. and McGrath, S.P. 2003. Uptake and distribution of nickel and other metals in the hyperaccumulator Berkheya coddii. *New Phytologist* 158(2):279-285.

Robinson, B.H., Bischofberger, S., Stoll, A., Schroer, D., Furrer, G., Roulier, S., Gruenwald, A., Attinger, W. and Schulin, R. 2008. Plant uptake of trace elements on a Swiss military shooting range: uptake pathways and land management implications. *Environmental Pollution* 153(3):668-676.

Romeiro, S., Lagôa, A.M., Furlani, P.R., Abreu, C.A.D., Abreu, M.F.D. and Erismann, N.M. 2006. Pb uptake and tolerance of Ricinus communis L. *Brazilian Journal of Plant Physiology* 18(4):483-489.

Rosenani, A.B., Fauziah, C.I. and Kala, D.R. 2008. Characterization of Malaysian sewage sludges and nitrogen mineralization in three soils treated with sewage sludge. *Malaysian Journal of Soil Science* 12:103-112.

Rubio, J.,Souza, M.L., and Smith, R.W. 2002. Overview of flotation as a wastewater technique. *J. of Mineral Engineering* 15:139-155.

Salleh, S., Majid, N. and Aziz, N.A.A. 2015. Effects of sewage sludge vermicompost and mineral fertilizer application on the aboveground Biomass and yield of maize (Zea mays). *J. Malays. Appl. Biol* 44(1):37-40.

Salt, D.E., Smith, R.D. and Raskin, I. 1998. Phytoremediation. *Annual review of plant biology* 49(1):643-668.

Sas-Nowosielska, A., Galimska-Stypa, R., Kucharski, R., Zielonka, U., Małkowski, E. and Gray, L. 2008. Remediation aspect of microbial changes of plant rhizosphere in mercury contaminated soil. *Environmental monitoring and assessment* 137(1):101-109.

Savci, S. 2012. An Agricultural Pollutant: Chemical Fertilizer. Int. J. of Env. Sci. and Development, Vol 3. No 1.

Schoonover, J.E., Crim, J.F., Williard, K.W., Groninger, J.W., Zaczek, J.J. and Pattumma, K. 2015. Sediment Dynamics Within Buffer Zone and Sinkhole Splay Areas Under Extreme Soil Disturbance Conditions. *Environmental management* 56(3):618-629.

Sharma, R.K. and Agrawal, M. 2005. Biological effects of heavy metals: an overview. *Journal of Environmental Biology* 26(2):301-313.

Shtangeeva, I. 2006. Phytoremediation of trace element contaminated soil with cereal crops: role of fertilizers and bacteria on bioavailability. Trace Elements in the Environment. Biogeochemistry, Biotechnology and Bioremediation, Prasad, MNV, KS Sajwan and R. Naidu (Eds.). CRC Press, Taylor and Francis Group, Boca Raton 549-581.

Smith, C.J., Hopmans, P. and Cook, F.J. 1996. Accumulation of Cr, Pb, Cu, Ni, Zn and Cd in soil following irrigation with treated urban effluent in Australia. *Environmental Pollution* 94(3):317-323.

Soudani, N., Najar-Souissi, S., Abderkader-Fernandez, V.K. and Ouederni, A. 2017. Effects of nitrogen plasma treatment on the surface characteristics of olive stone-based activated carbon. *Environmental technology* 38(8):956-966.

Speir, T.W., Van Schaik, A.P., Percival, H.J., Close, M.E. and Pang, L. 2003. Heavy metals in soil, plants and groundwater following high-rate sewage sludge application to land. *Water, Air, & Soil Pollution* 150(1):319-358.

Stacey, S., Merrington, G. and McLaughlin, M.J. 2001. The effect of aging biosolids on the availability of Cd and Zn in soil. *European Journal of Soil Science* 52(2):313-321.

Swenson, U. and Munzinger, J., 2010. Revision of Pycnandra subgenus Sebertia (Sapotaceae) and a generic key to the family in New Caledonia. Adansonia,
32(2):239-249.

Tabak, H.H., Lens, P., van Hullebusch, E.D. and Dejonghe, W. 2005. Developments in bioremediation of soils and sediments polluted with metals and radionuclides–1. Microbial processes and mechanisms affecting bioremediation of metal contamination and influencing metal toxicity and transport. *Reviews in Environmental Science and Biotechnology* 4(3):115-156.

Tian, H., Wang, S., Liu, J., Pan, S., Chen, H., Zhang, C. and Shi, X. 2006. Patterns of soil nitrogen storage in China. *Global Biogeochemical Cycles* 20(1).

U.S. EPA. 1990. "National Sewage Sludge Survey: Availability of Information and Data, and Anticipated Impacts of Proposed Rule on Proposed Regulations, Proposed Rule," Vol. 55, No. 218 Federal Register 47210–83.

U.S. EPA. 2000. Biosolids Technology Fact Sheet: Land Application of Biosolids, Office of Water, Washington, DC, USA.

Vesilind P. A.1994. The role of water in sludge dewatering. *Water EnvFe. Res.* 66:4-11.

Weiss, E.A. 2000. Oilseed crops. 2nd ed. Blackwell Science, Oxiford.

Weiss, E.A. 1971. Castor, sesame and safflower.

White, P. J., & Brown, P. H. 2010. Plant nutrition for sustainable development and global health. *Annals of Botany* 105(7):1073–1080.

Wilson, R., Van Schie, B.J. and Howes, D. 1998. Overview of the preparation, use and biological studies on polyglycerol polyricinoleate (PGPR). *Food and Chemical Toxicology* 36(9):711-718.

Yoon, J., Cao, X., Zhou, Q. and Ma, L.Q. 2006. Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *Science of the total Environment* 368(2):456-464.

Zarcinas, S., Fauziah, C.I., Mclaughlin, M.J., and Cozans, G. 2003. Heavy metals in soils and crops Southeast Asia (Peninsular Malaysia). *Env. Geochemist and Health* 26:560-564.

Zauyah, S., Juliana, B., Noorhafizah, R., Fauziah, C.I. and Rosenani, A.B. 2004, December. Content and speciation of heavy metals in some cultivated and uncultivated ultisols and inceptisols in peninsular Malaysia. In Australian New Zealand Soils Conference. Univ. of Sydney, Australia.

Zhang, X., Wang, H., He, L., Lu, K., Sarmah, A., Li, J., Bolan, N.S., Pei, J. and Huang, H. 2013. Using biochar for remediation of soils contaminated with heavy metals and organic pollutants. *Environmental Science and Pollution Research* 20(12):8472-8483.