UNIVERSITI PUTRA MALAYSIA

COPPER STATUS IN TROPICAL SOILS AND CRITICAL LEVELS FOR BRASSICA RAPA L. VAR. PARACHINENSIS

NURUL WAHIDA BINTI HANI

FP 2014 19

COPPER STATUS IN TROPICAL SOILS AND CRITICAL LEVELS FOR *BRASSICA RAPA* L. VAR. *PARACHINENSIS*

By

NURUL WAHIDA BINTI HANI

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

January 2014

DEDICATION

For my beloved grandmother, Haminah Kadir

And

The late Assoc. Prof. Dr. Anuar Abd Rahim

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

COPPER STATUS IN TROPICAL SOILS AND CRITICAL LEVELS FOR *BRASSICA RAPA* L. VAR. *PARACHINENSIS*

By

NURUL WAHIDA BINTI HANI

January 2014

Chair: Anuar Abd Rahim, PhD

Copper is one of the essential micronutrients required in small amounts however it will impair plant growth and cause toxicity when present in high concentrations. The use of agrochemicals in intensive agricultural land causes Cu build up in the soils. The availability of Cu to plants depends on its mobility which partly controlled by its association with soil constituents. The goals of this study were to assess the Cu concentration and phase associations in intensive vegetable farms; to evaluate Cu sorption-desorption in Oxisol, Inceptisol and Histosol; to evaluate *Brassica rapa* response to increasing soil Cu concentration and phase associations in the mineral soils.

Soil sampling took place in selected conventional and organic farms in Cameron Highlands, Pahang while one organic farm was chosen in Bangi, Selangor. Copper phase associations were analyzed using Cu sequential extraction (Salas *et al*., 1998) while soil pH, CEC, total carbon and free Fe, Al and Mn oxides were determined too. Assessment of soils in vegetable farms showed that soil Cu content in conventional (33.61 mg Cu kg^{-1}) and organic (11.91 mg Cu kg^{-1}) vegetable farms in the highland contained higher Cu than the forest soil (2.72 mg Cu kg^{-1}). There was no significant

difference in Cu content between soil of organic farms of highland (11.91 mg kg^{-1}) and lowland (12.79 mg kg^{-1}). This study found that the increase in Cu content was associated with higher pH, CEC and total carbon. Organic matter was found to be the main component that controls the fate of Cu in the cultivated soil under study. Longer operation farm period, routine application of fungicides and chicken manure leads to higher Cu concentration in conventional farm.

The Cu sorption isotherm was carried out in a batch experiment where 1:10 ratio of soil to solution equilibrated with 0.01M $CaCl_2$ solution containing 5, 10, 15, 20, 30, 60 and 100 mg L^{-1} Cu as $CuCl_2$, followed by desorption of Cu. Uncultivated soils from Oxisol (Munchong Series), Inceptisol (Selangor Series) and Histosol (peat) were used in this study. Results showed that Histosol had the highest sorption capacity followed by Oxisol and Inceptisol. The Freundlich model was found to be better in describing the sorption isotherms of Oxisol (74.82 L kg^{-1}, R^2=0.99) and Histosol (688.65 L kg^{-1}, R^2=0.99). Copper sorption in Inceptisol was well described (R^2=0.98) by the Langmuir model which provides the maximum adsorption value of 384.62 mg kg^{-1}. Histosol had the least tendency to desorb Cu followed by Oxisol and Inceptisol at 100 µg mL^{-1} Cu loading. The sorption-desorption capacity is influenced by the CEC, organic matter content, Fe and Al oxides and clays.

A factorial pot experiment was carried out to determine the Cu critical and toxicity threshold levels for *Brassica rapa* in Oxisol, Inceptisol and Histosol. Copper sulphate solution was applied at the rates of 0, 5, 10, 15, 20, 30 and 60 mg Cu kg^{-1} soil. The yield response of plant on Oxisol, Inceptisol and Histosol are expressed in quadratic equations of $y^{-1} = 1.422 \pm 0.244x + 0.014x^2$, $y^{-1} = 0.626 \pm 0.084x + 0.005x^2$ and $y = 1.678 + 0.198x \pm 0.007x^2$, respectively. The soil Cu critical level in Oxisol, Inceptisol and Histosol is 7.34, 5.96 and 7.40 mg kg^{-1}, respectively; and threshold toxicity level is 10.63, 10.92 and 21.64 mg kg^{-1}, respectively. Both Cu levels are in consistence with the soils desorption capacity and the concentration of Cu mobile fraction as defined as summation of water soluble and exchangeable fractions. Height of plants and the SPAD value of leaves decreased with increasing Cu concentration. Copper phase associations in Oxisol and Inceptisol were determined using sequential extraction method. Both soils were found to have the same order of Cu fractions of organic > residual > Fe/Mn oxides > carbonates > exchangeable > water soluble.

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

STATUS KUPRUM DALAM TANAH TROPIKA DAN PARAS KRITIKAL UNTUK *BRASSICA RAPA* L. VAR. *PARACHINENSIS*

Oleh

NURUL WAHIDA BINTI HANI

Januari 2014

Pengerusi: Anuar Abd Rahim, PhD

Kuprum (Cu) ialah salah satu mikronutrien penting yang diperlukan dalam kuantiti yang kecil. Tetapi ia boleh menjejaskan pertumbuhan tanaman dan menyebabkan ketoksikan dalam kuantiti tinggi. Penggunaan bahan kimia secara intensif dalam penanaman menyebabkan peningkatan konsentrasi Cu di dalam tanah. Ketersediaan Cu untuk tanaman bergantung kepada mobiliti yang dipengaruhi oleh ikatannya bersama komponen tanah. Objektif kajian ini ialah menilai kandungan dan sebaran Cu dalam tanah di kebun sayur ± sayuran; menilai keupayaan erapan-penyaherapan Cu dalam Oxisol, Inceptisol dan Histosol; menilai tindak balas *Brassica rapa* ke atas peningkatan konsentrasi Cu dan pecahan Cu dalam tanah mineral.

Pensampelan tanah dilakukan di sebuah kebun sayur konvensional dan organik di Cameron Highlands, Pahang manakala di Bangi, Selangor sebuah kebun sayur organik dipilih untuk penilaian kandungan Cu dalam tanah. Analisis fasa pecahan Cu dilakukan melalui kaedah pengekstrakan bersiri (Salas *et al*., 1998). Selain itu, analisis pH tanah, keupayaan penukaran kation, jumlah karbon dan oksida Fe, Al dan Mn juga dijalankan. Kandungan Cu di dalam tanah kebun sayur konvensional (33.61 mg kg^{-1}) dan organik (11.91 mg kg^{-1}) di kawasan tanah tinggi adalah lebih tinggi

daripada tanah hutan. Kandungan Cu di dalam tanah kebun sayur organik di kawasan tanah tinggi (11.91 mg kg^{-1}) tiada perbezaan ketara dengan tanah kebun sayur organik di kawasan tanah pamah (12.79 mg kg^{-1}).

Pemerhatian menunjukkan peningkatan konsentrasi kuprum ada perkaitan dengan peningkatan pH tanah, keupayaan penukaran kation dan jumlah karbon. Kajian ini mendapati bahan organik merupakan komponen utama dalam pecahan Cu dalam tanah kebun sayur - sayuran. Kandungan Cu dalam tanah kebun sayur konvensional adalah disebabkan oleh tempoh operasi kebun yang lebih panjang yang disertakan dengan penggunaan racun kulat dan aplikasi baja tahi ayam secara rutin.

Isoterma erapan Cu dijalankan melalui kaedah eksperimen bersiri di mana nisbah 1:10 tanah kepada larutan yang diseimbangkan dengan 0.01M $CaCl_2$ mengandungi 5,10, 15, 20, 30, 60 dan 100 mg L^{-1} Cu dalam $CuCl_2$, kemudian diikuti dengan isoterma penyaherapan. Tanah Oxisol (Siri Munchong), Inceptisol (Siri Selangor) dan Histosol (gambut) digunakan dalam eksperimen ini. Keputusan eksperimen keupayaan erapan-penyaherapan Cu di dalam Oxisol, Inceptisol dan Histosol menunjukkan Histosol mempunyai kadar erapan paling tinggi diikuti dengan Oxisol dan Inceptisol. Model Freundlich didapati lebih tepat dalam menunjukkan sifat erapan isoterma Oxisol (74.82 L kg^{-1}, R^2=0.99) dan Histosol (688.65 L kg^{-1}, R^2=0.99) manakala model Langmuir pula didapati lebih bersesuaian dengan sifat erapan Inceptisol, yang mengganggarkan maksimum erapan sebanyak 384.62 mg kg^{-1}. Pada konsentrasi 100 mg L^{-1}, Histosol menyaherap Cu paling rendah, diikuti dengan Oxisol dan Inceptisol.

Keupayaan erapan-penyaherapan dipengaruhi oleh keupayaan penukaran kation, bahan organik, Fe dan Al oksida serta lempung.

Sebuah faktorial eksperimen telah dijalankan untuk menentukan paras kritikal dan ketoksidan ambang Cu untuk Brassica rapa yang ditanam dalam Oxisol, Inceptisol dan Histosol. Larutan kuprum sulfat dicampurkan dengan tanah pada kadar 0, 5, 10, 15, 20, 30 dan 60 mg Cu kg^{-1} tanah. Respon hasil tanaman Oxisol, Inceptisol dan Histosol adalah kuadratik; $y^{-1}=1.422 \pm 0.244x+0.014x^2$, $y^{-1} = 0.626 \pm 0.084x+ 0.005x^2$ and $y = 1.678+0.198x \pm 0.007x^2$, bagi setiap order tanah. Paras kritikal Cu dalam tanah untuk Oxisol, Inceptisol and Histosol masing-masing ialah 7.34, 5.96 dan 7.40 mg kg^{-1} ; manakala tahap ketoksidan ambang ialah 10.63, 10.92 and 21.64 mg kg^{-1}, bagi setiap order tanah. Kedua ± dua tahap Cu adalah konsisten dengan keupayaan penyaherapan dan kepekatan pecahan mobil Cu. Ketinggian pokok dan nilai SPAD daun menurun dengan peningkatan kepekatan Cu. Pecahan Cu di dalam Oxisol dan Inceptisol ditentukan melalui pengekstrakan bersiri. Kedua ± dua tanah didapati mempunyai pecahan Cu mengikut turutan yang sama iaitu organik > sisa baki > Fe/Mn oksida > karbonat > pertukaran > larut air.

ACKNOWLEDGEMENTS

It is a pleasure to express my deep gratitude to the many people who have given their full support in making this thesis a magnificent experience. First and foremost, I want to thank The Most Gracious Allah swt for answering my prayers, giving me strength and patience in completing this thesis and who made all things possible for me.

I am heartily thankful to my supervisory committee members, the late Assoc. Prof. Dr. Anuar Abd. Rahim, Assoc. Prof. Dr. Che Fauziah Ishak and Assoc. Prof. Dr. Osumanu Haruna Ahmed, I am grateful and indebted to them for their expert and valuable guidance and encouragement extended to me. I wish to show my appreciation to my beloved parents, Hani Saad and Rathi Bakri, and my siblings Nadia, Syafiq, Nabilah and Farzana who inspired and encouraged me, for helping me to get through every trial that comes my way, and for all the emotional and financial support they gave me.

I like to thank all of my friends especially Arifa, Aeinna, Asma, Amielia, Hajar, Hun, Yit Leng, Rizal, Babak and others for giving me encouragement and moral support, cheering me up and stood by me through thick and thin. I take this opportunity to express my thanks to all the members of the Department of Land Management for their assistance and support. I also like to place on record, my sense and gratitude to all who either directly or indirectly, have lent their helping hands in this research project.

I certify that a Thesis Examination Committee has met on 3 January 2014 to conduct the final examination of Nurul Wahida binti Hani on her thesis entitled "Copper Status in Tropical Soils and Critical Levels for *Brasicca rapa* L. var. *parachinensis*" 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:

Christopher Teh Boon Sung, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Aminuddin bin Hussin, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Samsuri bin Abd. Wahid, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia
(Internal Examiner)

Sahibin bin Abd Rahim, PhD
Professor
Univesiti Kebangsaan Malaysia
Malaysia
(External Examiner)

NORITAH OMAR, PhD
Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17 February 2014

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

Anuar Abd Rahim, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Che Fauziah Ishak, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Osumanu Haruna Ahmed, PhD
Associate Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia
(Member)

____
BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

Declaration by Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citation have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of the 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 the 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, seminar 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 (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ______________________________ Date: 3 January 2014

Name and Matric No.: NURUL WAHIDA BINTI HANI (GS24128)

Declaration by Members of Supervisory Committee

- This is to confirm that the research conducted and the writing of this 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: ______________________

Signature: ______________________
Name of Chairman of Supervisory Committee: ______________________

Signature: ______________________
Name of Chairman of Supervisory Committee: ______________________

TABLE OF CONTENTS

		Page
ABSTRACT		ii
ABSTRAK		v
ACKNOWLEDGEMENTS		viii
APPROVAL		ix
DECLARATION		xi
LIST OF TABLES		xvi
LIST OF FIGURES		xvii
LIST OF ABBREVIATIONS		xix
CHAPTER		
1	**INTRODUCTION**	1
2	**LITERATURE REVIEW**	
	2.1 Tropical Soils	3
	2.1.1 Munchong Series (Oxisols)	3
	2.1.2 Selangor Series (Inceptisols)	3
	2.1.3 Peat (Histosols)	4
	2.2 Copper	4
	2.2.1 Characteristics of Copper	4
	2.2.2 Uses of Copper	5
	2.2.3 Copper in Soil	5
	2.2.4 Agrochemicals as the Source of Copper	5
	2.3 Fates of Copper in Soil	7
	2.3.1 Copper Fractions	8
	2.3.2 Formation of Ternary Complex	11
	2.4 Other Factors Affecting Copper Distribution in Soil	11
	2.4.1 pH	11
	2.4.2 Cation Exchange Capacity (CEC)	12
	2.5 Adsorption and Desorption Isotherms	12
	2.5.1 Adsorption Isotherms	12
	2.5.2 Desorption Isotherms	13
	2.6 Copper Content in Malaysian Agricultural Soil	14
	2.7 Toxicity Effects of Copper on Plant Growth	15
3	**GENERAL MATERIALS AND METHODS**	
	3.1 Soil pH	17
	3.2 Cation Exchange Capacity	17
	3.3 Total Carbon	17
	3.3 Free Fe, Al and Mn oxides	17
	3.4 Copper Sequential Extraction	18

4 **COPPER STATUS AND PHASE ASSOCIATIONS IN SOIL OF HIGHLAND AND LOWLAND VEGETABLE FARMS AND ITS RELATION TO SOIL PROPERTIES**

4.1 Introduction 19
4.2 Materials and Methods 20
4.2.1 Soil Sampling and Preparation 20
4.2.2 Physico-chemical Analyses 20
4.2.3 Data Analysis 20
4.3 Results and Discussion 20
4.3.1 Description of Sampling Sites in Highland Area 20
4.3.2 Chemical Properties of Soil in Highland Vegetable Farms 22
4.3.3 Copper Status and Phase Associations in Soil of Highland Vegetable Farm 23
4.3.4 Description of Sampling Sites in Lowland Area 26
4.3.5 Chemical Properties of Soil in Lowland Vegetable Farms 28
4.3.6 Copper Status and Phase Associations in Soil of Lowland Vegetable Farm 28
4.3.7 Comparison of Copper Content between Soil of Organic Farms in Highland and Lowland 29
4.4 Conclusion 31

5 **COPPER SORPTION AND DESORPTION ISOTHERMS IN OXISOL, INCEPTISOL AND HISTOSOL**

5.1 Introduction 32
5.2 Materials and Methods 33
5.2.1 Soil Sampling and Preparation 33
5.2.2 Physico-chemical Analyses 33
5.2.3 Sorption Isotherms 34
5.2.4 Desorption Isotherms 34
5.2.5 Data Analysis 35
5.2.6 Calculation 35
5.3 Results and Discussion 37
5.3.1 Soil Characteristics 37
5.3.2 Sorption in Oxisol, Inceptisol and Histosol 38
5.3.3 Sorption-Desorption Isotherms 40
5.3.4 Comparison of Sorption-Desorption in Oxisol, Inceptisol and Histosol 42
5.4 Conclusion 44

6 **EVALUATION ON *BRASSICA RAPA* L. VAR. *PARACHINENSIS* RESPONSE AND COPPER PHASE ASSOCIATIONS ON COPPER APPLICATION IN OXISOL, INCEPTISOL AND HISTOSOL**
6.1 Introduction 45
6.2 Materials and Methods 46
6.2.1 Field Experiments 46
6.2.2 Sample Preparation 46
6.2.3 Sequential Extraction 46
6.2.4 Data Analysis 46
6.3 Results and Discussion 47
6.3.1 Effects of Cu Application on Yield Response 47
6.3.2 Effects of Cu Application on Plant Height 49
6.3.3 Effects of Cu Application on SPAD Value of Leaves 52
6.3.4 Critical Soil Cu Level and Toxicity Threshold Limit for *Brassica rapa* Grown in Oxisol, Inceptisol and Histosol 56
6.3.5 Copper Phase Association in Oxisol and Inceptisol 57
6.4 Conclusion 64

7 **SUMMARY, CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH**
7.1 Summary 65
7.2 General Conclusion 66
7.3 Recommendation for Future Research 66

REFERENCES 67
APPENDICES 80
BIODATA OF STUDENT 85
LIST OF PUBLICATIONS 86

LIST OF TABLES

Table		Page
2.1	Copper-based inorganic pesticides	6
2.2	Copper containing-fertilizer materials	7
3.1	Sequential extraction procedure	18
4.1	Information on the conventional and organic vegetable farm in highland	20
4.2	Chemical properties of forest, conventional and organic vegetable farm soil in highland	22
4.3	Copper phase associations in forest, conventional and organic vegetable farm soil in highland	23
4.4	Information on the organic vegetable farm in lowland	26
4.5	Chemical properties in forest and organic vegetable farm soil in lowland	28
4.6	Copper phase associations in forest and organic vegetable farm soil in lowland	28
4.7	Copper phase associations in soil of organic vegetable farms in highland and lowland	30
5.1	Physico-chemical and mineralogical properties of Oxisol, Inceptisol and Histosol	37
5.2	The Freundlich and Langmuir constants for Oxisol, Inceptisol and Histosol	38
6.1	The critical and toxicity threshold level of Cu	56
6.2	Concentration of water soluble and exchangeable Cu fractions	57

LIST OF FIGURES

Figure		Page
2.1	The dynamic interrelationship between Cu pools in soil solution and Cu uptake by plant roots	8
2.2	Mechanism of Cu complexed by organic matter	9
2.3	Chemisorption of Cu^{2+} with surface hydroxyls on $Fe(OH)_3$	10
2.4	Nutritional and inhibitory effects of heavy metal concentration on living cells	15
4.1	Location of sampling sites in Cameron Highlands, Pahang	21
4.2	Copper fractions in forest, conventional and organic vegetable farm soil in highland	24
4.3	Location of sampling sites in Bangi, Selangor	27
4.4	Copper fractions in forest and organic vegetable farm soil in lowland	29
5.1	Sorption-desorption isotherms in Oxisol	40
5.2	Sorption-desorption isotherms in Inceptisol	41
5.3	Sorption-desorption isotherms in Histosol	41
5.4	Copper sorption in Oxisol, Inceptisol and Histosol	42
5.5	Copper desorption in Oxisol, Inceptisol and Histosol	43
6.1	Yield response to increasing Cu concentration in Oxisol	47
6.2	Yield response to increasing Cu concentration in Inceptisol	48
6.3	Yield response to increasing Cu concentration in Histosol	48
6.4	Plant height response to increasing Cu concentrations in Oxisol	50
6.5	Plant height response to increasing Cu concentrations in Inceptisol	50
6.6	Plant height response to increasing Cu concentrations in Histosol	51

6.7 SPAD value for leaves measured on plants grown in Oxisol of increasing Cu concentration 52

6.8 SPAD value for leaves measured on plants grown in Inceptisol of increasing Cu concentration 53

6.9 SPAD value for leaves measured on plants grown in Histosol of increasing Cu concentration 53

6.10 Visual symptom of Cu toxicity as shown by stunted growth and yellow colour of young leaves of two-week-old *Brassica rapa* grown on Oxisol, Inceptisol and Histosol 55

6.11 Water soluble fraction of Cu extracted from Oxisol and Inceptisol 58

6.12 Exchangeable fraction extracted from Oxisol and Inceptisol 59

6.13 Carbonate-bound fraction extracted from Oxisol and Inceptisol 60

6.14 Fe/Mn oxides-bound fraction extracted from Oxisol and Inceptisol 61

6.15 Organic fraction of Cu extracted from Oxisol and Inceptisol 62

6.16 Residual fraction of Cu extracted from Oxisol and Inceptisol 63

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CRD	Complete Randomized Design
EDTA	Ethylene-diamine-tetra-acetic acid
GML	Ground Magnesium Limestone
RCBD	Randomized Complete Block Design
SEP	Sequential Extraction Procedure
SNK	Students-Newman-Keuls

CHAPTER 1

INTRODUCTION

After World War II, the use of chemical fertilizers has increased worldwide. Ammonia-based fertilizers were new to the old-time farmers which was one of the drivers of the process of development in agriculture. Back then, farmers and scientists were told by the modern science that growing plants need at least 17 nutrients important to crops. They are nitrogen, phosphorus, potassium, calcium, magnesium and sulfur (macronutrients) and chlorine, boron, iron, manganese, zinc, copper and molybdenum (micronutrients).

One of the essential micronutrients needed by plants is copper (Cu). Copper plays a vital role in a large number of enzymes that are involved in cell metabolism. Thus, it is important for plant growth and development. Nevertheless, it is toxic to plants and soil biota when present in excess. The obvious visual symptoms of Cu toxicity are chlorosis followed by necrosis. The sources of Cu introduced to the cultivation area are such as chemical and organic fertilizers, sewage sludge and fungicides.

In 2009, the total vegetable area in Malaysia were 41, 078 ha with 623, 457 tonnes production. The area increased in 2010 to 52, 793 ha and total production of 870, 251 tonnes vegetables (Statistik Tanaman, 2012). In the near future, there will be limited land for agricultural use due to increasing urbanization, commercial plantations and others. Indirectly, this will have implications on soil sustainability. More application of fertilizers, pesticides and other anthropogenic input will be used to grow large scale of crops in order to meet demand. These practices are common soils of where vegetables are grown intensively. Heavy use of these materials with time, would lead to depletion in soil quality, groundwater contamination and direct exposure to human health.

Copper is widely known for its specific adsorption with soil constituents. It is very tightly held with both inorganic and organic exchange sites. The processes that control its association with soil constituents are such as adsorption, occlusion and co-precipitation, organic chelation and complexion and microbial fixation. Therefore, Cu distribution varies with soils in accordance with the type and amount of each soil components present. Copper association with the soil components has direct influence on the equilibrium concentration between soils solid and liquid phases. In other words, Cu availability and toxicity to plants is controlled by sorption-desorption mechanisms.

Large application of anthropogenic sources elevate Cu concentration in soil with time. Hence, it is important to assess the Cu content in soils under intensified vegetable cultivation in order to know the degree of Cu contamination and Cu phase association. Different sorption-desorption capacity of Cu and its versatility to bind onto various soil constituents gives impact on Cu forms, plant availability and toxicity especially on tropical soils of varying physico-chemical properties. Therefore, it is interesting and a good concern to study Cu behaviour in term of its sorption-desorption capacity, phase association in soil and its toxicity to plant grown on selected tropical soils. This will provide information of concentration of Cu available for plant with respect to type of soil system under study. Besides that, one is able to estimate required rates of Cu fertilizer to avoid the wastage of resources and avoid soil, plant and water contamination.

The specific objectives of this study were to:

1. evaluate and compare Cu status and phase associations in soil of highland and lowland vegetable farms
2. evaluate sorption and desorption behaviour of Cu in Oxisol, Inceptisol and Histosol
3. evaluate *Brassica rapa* growth response and to determine the Cu critical, threshold toxic level of soil in Cu amended Oxisol, Inceptisol and Histosol; and to evaluate the Cu phase associations in Oxisol and Inceptisol.

REFERENCES

Ahmad, I., Hayat, S. and Pitchel, J. 2005. Heavy metal contamination of soil: Problems and Remedies. pp. 252. U.S.A.: Science Publishers.

Ahumada, I., Mendoza, J. and Ascar, L. 1999. Sequential extraction of heavy metals in soils irrigated with wastewater. *Communication Soil Science Plant Analysis* 30:1507–1519.

Aiken, G. R., McKnight, D.M., Wershaw, R.L and MacCarty, P. 1985. Humic Substances in Soil, Sediment, and Water. Geochemistry, Isolation, and Characterization. New York: John Wiley & Sons.

Aini, Z. and Vimala, P. 2002. Research and development of organic crop production in Malaysia. Expert Group Workshop on Preparation of Technical Guidelines on Organic Cultivation of Tropical and Subtropicals Fruits, INTAN Bukit Kiara, Kuala Lumpur, Malaysia.

Akma, N.M.H., Samsuri, A.W., Ainie, H.K. and Rosenani, A.B. 2009. Sorption-Desorption Study of a Herbicide 2,4-Dichlorophenoxyacetic Acid on Acidic Tropical Soils. *Malaysian Journal of Soil Science* 13:119-131.

Alcacio, T.E., Hesterberg, D., Chou,W.Q., Martin, J.D., Beauchemin, S. and Sayers, D.E. 2001. Molecular scale characteristics of Cu(II) bonding in goethite-humate complexes. Geochim. Cosmochim. Acta 65:1355-1366.

Alloway, B.J. 1995. Heavy Metals in Soils (2nd ed.). pp. 18-21. London: Blackie Academic & Professional.

Alva, A.K. and Graham, J.H.1991. The role of copper in citriculture. *Advances in Agronomy* 1:145–170.

Alva, A.K., Huang, B. and Paramasivan, S. 2000. Soil pH affects copper fraction and phytotoxicity. *American Journal of Soil Science* 64:955-962.

Aminuddin, B.Y. 1994. Tropical Peat: Proceedings of the International Symposium on Tropical Peatland, 6–10 May 1991, Kuching, Sarawak, Malaysia.

Anda, M., Shamshuddin, J., Fauziah, I. and Syed Omar, S.R. 2008. Mineralogy and factors controlling charge development of three Oxisols developed from different parent materials. *Geoderma* 143:153-167.

Apak, R. 2002. In: Encyclopedia of Surface and Colloid Science, ed. A. Hubbard, pp. 385. New York: Marcel Dekker Inc.

Arias, M., Barral, M.T. and Mejuto, J.C. 2002. Enhancement of copper and cadmium adsorption on kaolin by the presence of humic acids. *Chemosphere* 48:1081-1088.

Arias, M., Pérez-Novo, C., Osorio, F., López, E. and Soto, B. 2005. Adsorption and desorption of copper and zinc in the surface layer of acid soils. *Journal of Colloid and Interface Science* 288:21-29.

Atanassova, I.D. 1995. Adsorption and desorption of Cu at high equilibrium concentrations by soil and clay samples from Bulgaria. *Environmental Pollution* 87: 17-21.

Babu, T.S., Marder, J.B., Tripuranthakam, S., Dixon, D.G., Greenberg, B.M. 2001. Synergistic effects of a phoyooxidized polycylic aromatic hydrocarbon and copper on photosynthesis and plant growth: Evidence that in vivo formation of reactive oxygen species is a mechanism of Cu toxicity. *Environmental Toxicology and Chemistry* 20: 1351-1358.

Badri, M.A. 1984. Identification of heavy metal toxicology levels in soil waste by chemical speciation. *Conservation Recycling* 7:25-270.

Barrow, N.J. 1987. Reactions with variable-charge soils. Dordrecht: Martinus Nijhoff Publication.

Basta, N.T. and McGowen, S.L. 2004. Evaluation of chemical immobilization treatments for reducing heavy metal transport in a smelter contaminated soil. *Environmental Pollution* 127:78-82.

Benton, J. 2003. Agronomic handbook: management of crops, soils, and their fertility. pp. 274. U.S.A.: CRC Press.

Bernal, M., Sanchez-Testillano, P., Risueno, M.C. and Yruela, I. 2006. Excess copper induces structural changes in cultured photosynthetic soybean cells. *Functional Plant Biology* 33:1001-1012.

Bradl, H.B. 2004. Adsorption of heavy metals ions on soils and soils constituents. *Journal of Colloid and Interface Science* 277: 1-18.

Brady, N.C. and Weil, R.R. 1990. The nature and properties of soils (10th ed.). New York: Macmillan Publisher.

Brun, L.A., Maillet, J. Richarte, J., Hermann, P. and Remy, J.C. 1998. Relationships between extractable copper, soil properties and copper uptake by wild plants in vineyard soils. *Environmental Pollution* 102: 151-161.

Brun, L.A., Maillet, J., Hinsinger, P. and Pepin, M. 2001. Evaluation of copper availability to plants in copper-contaminated vineyard soils. *Environmental Pollution* 111:293-302.

Buchter, B., Davidoff, B., Amacher, M.C., Hinz, C., Iskandar, I.K. and Selim, H.M. 1989. Correlation of Freundlich Kd and retention parameters with soils and elements. *Soil Science* 148:370-379.

Cairney, T. 1993. Contaminated Land: Problems and Solutions. pp. 351. New York: Blackie Academic & Professional.

Cang, L.,Wang, Y.J., Zhou, D.M. and Dong, Y.H. 2004. Heavy metals pollution in poultry and livestock feeds and manures under intensive farming in Jiangsu Province, China. *Journal of Environmental Sciences* 16:371-374.

Caspi, V., Droppa, M., Horvath, G., Malkin, S., Marder, J.B. and Raskin, V.I. 1999. The effect of copper on chlorophyll organization during greening of barley leaves. *Photosynthesis Res* 62:165-174.

Cavallaro, N. and McBride, M.B. 1984. Zinc and copper sorption and fixation by acid soil clay: Effect of selective dissolutions. *Soil Science Society of American Journal* 48:1050-1054.

Clymo, R.S. 1983. Peat. In: Ecosysrems of the world 4A, mires: swamp, bog, fen and moor. ed. A.J.P. Gore. pp. 159-224. Amsterdam: Elsevier.

Dai, J., Becquer, T., Rouiller, J.H., Reversat, G., Bernhard-Reversat, F., Nahmani, J. and Lavelle, P. 2004. Heavy metal accumulation by two earthworm species and its relationship to total and DTPA-extractable metals in soil. *Soil Biology and Biochemistry* 36: 91-98.

Davis, J.A. 1984. Complexation of trace metals by adsorbed natural organic matter. *Geochim Cosmochim Acta* 48: 679-691.

Davis, J.R. 2001. ASM Specialty Handbook: Copper and Copper Alloys. Applications. pp. 153. USA: ASM International.

Drinkwater, L.E., Letourneau, D.K., Workneh, F., van Bruggen, A.H.C., Shennan, C., 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. *Applied Ecology* 5: 1098–1112.

FAO-UNESCO, 1990. Guidelines for soil description (3rd ed). Food and Agriculture Organization, Rome.

Farrell, J. and Reinhard, M. 1994. Desorption of halogenated organics from model solids, sediments and soil under unsaturated conditions. *Kinetics, Environmental Science and Technology* 28:63-72.

Fauziah, C.I., Rozita, O., Zauyah, S., Anuar, A.R. and Shamsuddin, J. 2001. Heavy metals content in soils of Peninsular Malaysia Grown with cocoa and in cocoa tissues. *Malaysian Journal of Soil Science* 5: 47-58.

Fernandes, J.C. and Henriques, F.S. 1991. Biochemical, physiological, and structural effects of excess copper in plants. *Botanical Review* 57: 246–273.

Flemming, C.A. and Trevors, J.T. 1989. Copper toxicity and chemistry in the environment: A review. *Water, Air and Soil Pollution* 44: 143-158.

Flores-Veles, L.M., Ducaroir, J., Jaunet, A.M., and Robert, M. 1996. Study of the distribution of copper in an acid sandy vine yard soil by three different methods. *European Journal of Soil Science* 47: 523-532.

Ford, R.G., Bertsch, P.M. and Farley, K.J. 1997. Changes in transition and heavy metal partitioning during iron hydrous oxides aging. *Environmental Science and Technology* 31:2028-2033.

Gee, G.W. and Bauder, J.W. 1986. Particle-size analysis. In Methods of Soil Analysis Part 1 Physical and Minerological Methods (2nd ed.). ed. A. Klute. pp. 383-411. Wisconsin: ASA-SSSA.

Gonzalez, R.C., Jirka, S., Sauve, S. and Adriano, D. 2006. Mechanisms and Pathways of Trace Element Mobility in Soils. *Advances in Agronomy* 91:111-177.

Guo, X.Y., Zuo, Y.B., Wang, B.R., Li, J.M., Ma, Y.B. 2010. Toxicity and accumulation of copper and nickel in maize plants cropped on calcareous and acidic field soils. *Plant and Soil* 333:365-373.

Gupta, S.K. and Aten, C. 1993. Comparison and evaluation of extraction media and their suitability in a simple model to predict the biological relevance of heavy metal concentrations in contaminated soils. *International Journal of Environmental and Analytical Chemistry* 51:25-46.

Harter, R.D. 1991. Micronutrient adsorption-desorption reactions in soils. In Micronutrients in Agriculture. pp. 59-87. ed. J.J. Mortvedt, F.R. Cox, L.M. Shuman, and R.M. Welch. Madison: Soil Science Society of America.

Havlin, J.L., Beaton, J.D., Tisdale, S.L. and Nelson, W.L. 1999. Soil Fertility and Fertilizers An Introduction to Nutrient Management. pp. 265-271. New Jersey: Prentice-Hall.

He, M.M., Tian, G.M., Liang, X.Q., Yu, Y.T., Wu, J.Y. and Zhou, G.D. 2007. Effects of two sludge application on fractionation and phytotoxicity of zinc and copper in soil. *Journal of Environmental Sciences* 19:1482-1490.

Hogg, D.S., Mclaren, R.G. and Swift, R.S. 1993. Desorption of copper from some New Zealand soils. *Soil Science Society of American Journal*. 57:361-366.

Hooda, P.S. 2010. Trace elements in soils. Pp. 25. United Kingdom: Blackwell Publishing Ltd.

Huang, W. and Weber, J.R. 1997. A distributed reactivity model for sorption by soils and sediments. Relationship between desorption, hysteresis and the chemical characteristics of organic domains. *Environmental Science Technology* 31: 2562-2569.

Impellitteri, C.A., Y., Lu, J.K., Saxe, H.E., Allen and W.J.G.M. Peijnenburg. 2002. Correlation of the portioning of dissolved organic matter fractions with the desorption of Cd, Cu, Ni, Pb, and Zn from 18 Dutch soils. *Environ. Intern.* 28:401-410.

Inada, K., 1963. Studies on a method for determining deepness of green color and chlorophyll content of intact crop leaves and its practical applications. 1. Principle for estimating the deepness of green color and chlorophyll content of whole leaves. Proceeding of the Crop Science Society of Japan, 32: 157-162.

International Peat Society, 1997 – IPS. On peat and peatlands: a short introduction. http://www.peatsociety.fi (accessed on 29th April 2012).

Janik, E., Maksymiec, W., Gruszecki, W.I. 2010. The photoprotective mechanisms in Secale cereal leaves under Cu and high light stress condition. *J. Photoc. Photobio. B* 101:47-52.

Janssen, B., Mulder, J. and Verstraten, J.M. 2003. Organic complexation of Al and Fe in acidic soil solutions – Comparison of diffusive gradients in thin films analyses with Models V and VI predictions. *Analytica Chimica Acta* 498:105–117.

Jenne, E.A. 1968. Controls on Mn, Fe, Co, Ni, Cu and Zn concentrations in soils and water: the significant role of hydrous Mn and Fe oxides. In Trace inorganics in water. Advances in chemistry. ed. Gould, R.F. American Chemical Society. 73:337-387.

Jjemba, P.K. 2004. Environmental microbiology: principles and applications. pp. 372. USA: Science Publishers.

Jordão, C. P.; Alves, N. M.; Pereira, J. L. and Bellato, C. R. 2000. Adsorption of Cu^{2+} ions by a humic yellow red oxisol. *Quím Nova* 23:5-11.

Juliana, B. 2006. Masters Thesis. Assessment of heavy metal concentrations in vegetables and different soil types in the Kluang-Kota Tinggi area, Johore, Malaysia. Universiti Putra Malaysia, 2006.

Juo, Anthony S.R. and Kathrin Franzluebbers. 2003. Tropical Soils: Properties and Management for Sustainable Agriculture. New York: Oxford University Press Inc.

Kabata-Pendias, A. and Pendias, H. 2001. Trace Elements in Soils and Plants (3rd ed). pp. 106-119. New York: CRC Press.

Kanakaraju, D., A.M., Aa'in and A., Khairulanwar. 2007. Relationship between metals in vegetables with soils in farmlands of Kuching, Sarawak. *Malaysian Journal of Soil Science* 11: 57-69.

Kariya, K., A. Matsuzaki and Machida, H. 1982. Distribution of chlorophyll content in leaf blade of rice plant. *Japanese Journal of Crop Science* 51: 134-135.

Khairiah, J., Habibah, J., Ahmad-Mahir, R., Maimon, A., Aminah, A. and Ismail, B.S. 2009. Studies on heavy metal deposits in soils from selected agricultural areas of Malaysia. *Advances in Environmental Biology* 3:329-336.

Khairiah, J., Lim, K.H., Ahmad-Mahir, R. and Ismail, B.S. 2006. Heavy metals from agricultural soils from Cameron Highlands, Pahang and Cheras, Kuala Lumpur, Malaysia. *Bulletin of Environmental Contamination and Toxicology* 77:608-615.

Kile, D.E., Wershaw, R.L. and Chiou, C.T. 1999. Correlation of soil and sediment organic matter polarity to aqueous sorption of nonionic compounds. *Environmental Science and Technology* 33: 2053-2056.

Krebs, R., S.K., Gupta, G., Furrer and Schulin, R.. 1998. Solubility and plant uptake of metals with and without liming of sludge-amended soils. *Journal of Environmental Quality* 27:18-23.

Komárek, M., Vaněk, A., Chrastný, V., Száková, J., Kubová, K., Drahota, P. 2009b. Retention of copper originating from different fungicides in contrasting soil types. *Journal of Hazardous Materials* 166:1395–402.

Kupper, H. and Kroneck, P.M.H. 2005. Heavy metal uptake by plants and cyanobacteria. *Met Ions Biol Syst* 44:97-142.

Li, T. and Z.T., Xiong. 2004. A novel response of wild-type duckweed (*Lemna paucicostata Hegelm*.) to heavy metals. *Environmental Toxicology* 9:95–102.

Li, W.Q., Zhang, M. and Shu, H.R. 2005. Copper in soils of apple orchards. *Environmental Science and Pollution Research* 12:168-172.

Li, Y.X., Li, W., Wu, J., Xu, L.C., Su, Q.H. and Xiong, X. 2007a. Contribution of additives Cu to its accumulation in pig feces: study in Beijing and Fuxin of China. *Journal of Environmentaal Sciences* 19: 610-5.

Liu, D.H., Jiang, W.S. and Hou, W.Q. 2001. Uptake and accumulation of copper by roots and shoots of maize (Zea mays L.) *Journal of Environmental Science* (*China*) 13: 228-232.

Logan, T.J., B.J., Lindsay, L.E., Goins and Ryan, J.A. 1997. Field assessment of sludge metal bioavailability to crops: sludge rate response. *Journal of Environmental Quality* 26: 534-50.

Loland, J.O and Singh, B.R. 2004. Copper contamination of soil and vegetation in coffee orchards after long-term use of Cu fungicides. *Nutrient Cycling in Agroecosystems* 69: 203-211.

Lu, A.X., S.Z., Zhang and Shan, X.Q.. 2005. Time effect on the fractionation of heavy metals in soils. *Geoderma* 125: 225-234.

Luna, C.M., Gonzalez, C.A. and Trippi, V.S. 1994. Oxidative damage caused by excess of copper in oat leaves. *Plant Cell Physiology* 35:11-15.

Maksymiec, W., Russa, R., Urbanik-Sypniewska, T. and Baszynski, T. 1994. Effect of excess Cu on the photosynthetic apparatus of runner bean leaves treated at two different growth stages. *Physiology Plant* 91:715-721.

Mallick, N. and Mohn, F.H. 2003. Use of chlorophyll fluorescence in metal-stress research: a case study with the green microalga Scenedesmus. *Ecotoxicology and Environmental Safety* 55:64-69.

Maltby, E. and Immirzi, P.1993. Carbon dynamics in peatlands and other wetland soils. Regional and global perspectives. *Chemosphere* 27: 999-1023.

Mazlan, N. and Mumford, J., 2005. Insecticide use in cabbage pest management in the Cameron Highlands, Malaysia. *Crop Protection* 24: 31–39.

McBride, M. 1994. Environmental Chemistry of Soils. In *Trace Elements In Terrestrial Environments: biogeochemistry, bioavailability and risks of metals*, ed. Adriano, D.C., pp. 43. New York: Springer-Verlag.

McIntyre, D.S. and J., Loveday. 1974. Bulk density. In Methods of Analysis for Irrigated Soils. Commonwealth Agricultural Bureaux Technical Commmunication No. 54. e.d. Loveday, J. Farnham Royal, England.

McLaughlin, M.J., R.E., Hamon, R.B., Mc Laren, T.W., Speir and Rogers, S.L. 2000. Effect of chloride in soil solution on the plant availability of biosolid-borne cadmium. *Australian Journal of Soil Research* 38:1037-1086.

Mehra, O.P. and Jackson, M.L. 1990. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. *Clays and Clay Minerals*. 7:317-327.

Moeskops, B., Sukristiyonubowo, Buchan, D., Sleutel, S., Herawaty, L., Husen, E., Saraswati, R., Setyorini, D., De Neve, S., 2010. Soil microbial communities and activities under intensive organic and conventional vegetable farming in West Java, Indonesia. *Appllied Soil Ecology* 45:112–120.

Mokolabate, M.S. and Haynes, R.J. 2002. Comparative liming effect of four organic residues applied to an acid soil. *Biology and Fertility of Soils* 35: 79-85.

Msaky, J.J. and Calvert, R.1990. Adsorption behavior of copper and zinc in soil influence of pH on adsorption characteristics. *Soil Science* 150:513–522.

Murray, K.S., Rogers, D.T. and Kaufman, M.M. 2004. Heavy metals in an urban watershed in Southeastern Michigan. *Journal of Environmental Quality* 33:163-172.

Naiyanan, A. and Banchagan, W. 2006. Phytoremediation of Copper Contaminated Soil by *Brassica juncea* (L.) Czern and *Bidens alba* (L.) DC. var. *radiata*. *Journal of Science and Research Chulalongkorn University* 31: 49-56.

Nicholson, F.A., Chambers, B.J., Williams, J.R. and Unwin, R.J. 1999. Heavy metals contents of livetstock feeds and animal manures in England and Wales. *Bioresource Technology* 70:1 23-31.

Oquist, K.A., Strock, J.S. and Mulla, D.J. 2007. Influence of alternative and conventional farming practices on subsurface drainage and water quality. *Journal of Environmental Quality* 36: 1194-1204.

Ouzounidou, G. 1994. Copper-induced changes on growth, metal content and photosynthetic function of Alyssum montanum L. plants. *Environmental and Experimental Botany* 34:165-172.

Ouzounidou, G., M., Ciamporova, M., Moustakas and Karataglis, S. 1995. Responses of maize (*Zea mays* L.) plants to copper stress I. Growth, mineral content and ultrastructure of roots. *Environmental and Experimental Botany* 35:167-176.

Page, S.E., Wust, R.A.J., Weiss, D., Rieley, J.O., Shotyk, W. and Limin, S.H. 2004. A record of Late Pleistocene and Holocene carbon accumulation and climate change from an equatorial peat bog (Kalimantan, Indonesia): implications for past, present and future carbon dynamics. *Journal of Quaternary Science* 19: 625:635.

Paramananthan, S. 1978. Register of Soils: Peninsular Malaysia. Ministry of Agriculture, Division of Agriculture. Kuala Lumpur, Malaysia.

Paramananthan, S. 2000. Soils of Malaysia: Their characteristics and identification. Academy of Sciences Malaysia, Kuala Lumpur.

Peech, H.M. 1965. Hydrogen-ion activity. In Methods of soil analysis, Part 2, ed. C.A. Black, D.D. Evans, L.E., Ensminger, J.L., White, F.E., Clark, R.C., Dinauer. Madison, W.I. pp. 914-926. American Society of Agronomy.

Perminova, I.V., N.Y., Grechhischeva and Petrosyan, V.S.. 1999. Relationships between structure and binding affinity of humic substances for polycyclic aromatic hydrocarbons: relevance of molecular descriptors. *Environmental of Science and Technology* 33: 3781-3787.

Petruzzelli, G., Guidi, G., Lubrano, L. 1985. Ionic strength effect on heavy metal adsorption by soil. *Communications in Soil Science and Plant Analysis* 16: 971-986.

Peverill, K.I., Sparrow, L.A. and Reuter, D.J. 1999. Soil Analysis – An Interpretation Manual. pp. 369. Australia: CSIRO Publishing.

Polak, B. 1975. Character and occurrence of peat deposits in the Malayan Tropics. In Proceeding of the Symposium Modern Quaternary Research in Indonesia. pp. 71-81.

Prasad, M.N.V. and Strzalka, K. 1999. Impact of heavy metals on photosynthesis. In Heavy Metal Stress in Plants. e.d. Prasad, M.N.V. and Hagemeyer, J. pp. 117-138. Berlin: Springer Publishers.

Prasad, R. and Power, J.F. 1997. Soil Fertility Management for Sustainable Agriculture. pp. 270-272. New York : CRC Press.

Reimann, P. and de Caritat, P. 1998. Chemical elements in the environment. New York: Springer-Verlag.

Rerkasem, B., 2005. Transforming subsistence cropping in Asia. *Plant Production Science* 8:275–287.

Reuther, W. and C.K., Labanauskas. 1966. Copper. In Diagnostic Criteria for Plants and Soils. pp. 157-159. e.d. Chapman, H.D. U.S.A: University of California.

Rocha, J.C. and Rosa A.H. 2003. Aquatic humic substances. Species interaction with metal. Sao Paulo: UNESP.

Rodriguez, B. and Ramirez, R. 2005. A soil test for determining available copper in acidic soils of Veneuzuela. *Interciencia* 30: 361-364.

Rodriguez-Rubio, P., Morillo, E., Madrid, L., Undabeytia, T. and Maqueda, C. 2003. Retention of copper by calcareous soil and its textural fractions influence of amendment with two agroindustrial residues. *European Journal of Soil Science* 54:401-409.

Rosazlin, A., I., Che Fauziah, A.B., Rosenani and Zauyah, S. 2006. Domestic sewage sludge application on an acid tropical soil: Part II. Heave metals uptake by maize and accumulation in the soil. *Malaysia Journal of Soil Science* 10:35-52.

Rybicka, E.H., Calmano, W. and Breeger, A. 1995. Heavy metals sorption/desorption on competing clay minerals and experimental study. *Applied Clay Science* 9:369-381.

Sahibin A.R., Zulfahmi A.R., Lai K.M., Errol P. and Talib M.L. Heavy metals content of soil under vegetables cultivation in Cameron Highland. Proceedings of the Regional Symposium on Environment and Natural Resources, Kuala Lumpur, Malaysia, 10-11th April 2002. Omar, R., Ali Rahman, Z., Latif, M.T., Lihan, T. and Adam J.H. (Eds.), Vol 1: 660-667.

Salas, F.M., Chino, M., Goto, S., Igarashi, T., Masujima, H. and Kumazawa, K. 1998. Forms and distribution of heavy metals in soils long term applied with sewage sludge. *Journal of International Society for Southeast Asian Agricultural Sciences* 4: 64-98.

Schmwertmann, U. and Cornell, R.M. 1991. Iron oxides in the laboratory: Preparation and characterization. New York: VCH Publishers, Inc.

Schroer, S., Sulistyanto, D. and Ehlers, R.U. 2005. Control of Plutella xylostella using polymer-formulated Steinernema carpocapsae and Bacillus thuringiensis in cabbage fields. *Journal of Applied Entomology* 129: 198–204.

Schulten, H.R., Plage, B. and Schitzner, M. 1991. A chemical structure for humic substances. *Naturwissenschaften* 78: 311-312.

SenGupta, A.K. Environmental Separation of Heavy Metals Engineering Process. pp. 2. U.S.A.: Lewis Pubslihers.

Shamshuddin, J. and Darus, A. 1979. Mineralogy and Genesis of Soils in Universiti Pertanian Malaysia, Serdang Selangor. *Pertanika* 2:141-148.

Sheldon, A.R. and Menzies, N.W. 2005. The effect of copper toxicity on the growth and root morphology of Rhodes grass (*Chloris gayana* Knuth.) in resin buffered solution culture. *Plant and Soil* 278:341-349.

Shuman, L.M. 1991. Chemical forms of micronutrients in soils. In Micronutrients in Agriculture (2nd ed). e.d. J.J. Morvedt. Madison: Soil Science Society of America.

Silveira, M.L.A, Alleoni, L.R.F. and Giulherme, L.R.G. 2003. Review: Biosolids and heavy metals in soils. *Scientia Agricola* 60:793-806.

Silveira, M.L.A. and Alleoni, L.R.F. 2003. Copper adsorption in tropical Oxisols. *Brazilian Archives of Biology and Technology* 46: 529-536.

Singh, B.R. 1997. Soil pollution and contamination. In Methods for Assessment of Soil Degradation. pp. 279-299. e.d. R. Lal. Boca Raton: CRC Press.

Singh, D., McLaren, R.G. and Cameron, K.C. 2006. Zinc sorption-desorption by soils: effect of concentration and length of contact period. *Geoderma* 137:117-125.

Sonmez, S., M., Kaplan, N.K., Sonmez, H., Kaya and I., Uz. 2006. High level of copper application to soil and leaves reduce the growth and yield of tomato plants. *Scientia Agricola* 63: 213-218.

South, D.B. 2002. Inorganic Pesticides. In: Encyclopedia of Pest Management Vol. 1. ed. Pimentel, D. pp. 396. New York: Marcel Dekker Inc. New York.

Sparks, D.L. 1995. Sorption phenomena on soils. In Environmental soil chemistry. pp. 99-139. e.d. Sparks, D.L. San Diego, California.

Sposito, G., L.J., Lund and Chang, A.C.. 1982. Trace metal chemistry in arid-zone fields amended with sewage sludge: I. Fractionation of Ni, Cu, Zn, Cd and Pb in solid phases. *American Journal of Soil Science* 46: 260-264.

Stamatiadis, S., Werner, M., Buchanan, M., 1999. Field assessment of soil quality as affected by compost and fertilizer application in a broccoli field (San Benito County, California). *Appllied Soil Ecology* 12: 217–225.

Statistik Tanaman (Sub Sektor Tanaman Makanan) 2012. Unit Perangkaan Bahagian Perancangan, Teknologi Maklumat dan Komunikasi Jabatan Pertanian Semenanjung Malaysia.

Stehouwer, R.C., A.M. Wolf, and W. Dotty. 2000. Chemical monitoring of sewage sludge in Pennsylvania: Variability and application uncertainty. *Journal of Environmental Quality* 29:1686-1695.

Stevenson, F.J and Ardakani, M.S. 1972. Organic matter reactions involving micronutrients in soils. In Micronutrients in Agriculture. pp. 79-114. e.d. Moervedt, J.J., Giordano, P.M., Lindsay, W.L. Madison: Soil Science Society of America.

Stevenson, F.J. 1994. Humus Chemistry: Genesis, Composition, Reactions (2nd Ed.). New York: Wiley-Interscience.

Stumn, W. and Morgan, J.J. 1981. Aquatic Chemistry. New York: John Wiley & Sons.

Swift R.S. and McLaren R.G. 1991. Micronutrient sorption by soils and soil colloids. In: Interactions at the soil colloid-soil solution interface. ed. Bolt G.H. pp. 235-243. Dordrecht: Kluwer Academic Publication.

Szalontai, B., Horvath, L.I., Debrezeny, M., Droppa, M and Horvath, G. 1999. Molecular rearrangements of thylakoids after heavy metal poisoning, as seen by Fourier transform infrared (FTIR) and electron spin resonance (ESR) spectroscopy. *Photosynthesis Research*. 61:241-252.

Tan, K.H. 2005. Soil Sampling, Preparation and Analysis. 2nd ed. pp. 186. Boca Raton : CRC Press

Teh, C.B.S. and Rashid, M.A. 2003. Object-oriented code to lookup soil texture classes based on any soil classification scheme. *Communication in Soil Science and Plant Analysis* 34:1-11.

Temminghoff, E. J. M., Van Der Zee, S. E. A. T. M. and Keizer, M. G. 1994. The influence of pH on the desorption and speciation of copper in a sandy soil. *Journal of Soil Science* 158:398-407.

Temminghoff, E.J.M., S.E.A.T.M., van der Zee and F.A.M., de Hann. 1997. Copper mobility in a copper-contaminated sandy soil as affected by pH and solid and dissolves organic matter. *Environmental Science* and *Technology* 31: 1109-1115.

Tessens, E. and Shamshuddin, J. 1983. Mineralogy and Genesis of Soils in Universiti Pertanian Malaysia, Serdang, Selangor. *Pertanika* 2: 141-148.

Tessier, A., P.G.C., Campbell and M., Bisson. 1979. Sequential extraction procedure for the speciation of particulate trace metals. *Analytical Chemistry* 51:844–851.

Thompson, G.T., 1998. Consumer demand for organic foods: what we know and what we need to know. *American Journal of Agricultural Economics* 80: 1113–1118.

Tiege, M., Huchzermeyer, B. and Schultz, G. 1990. Inhibition of chloroplast ATP synthetase/ATPase is the primary effect of heavy metal toxicity in spinach plants. *Biochemie und Physiologie der Pflanzen* 186: 165-168.

Uehara, G. 1988. Acric properties and their significance to soil classification. Paper presented at 8th International Soil Classification Workshop, Rio de Janeiro : Embrapa, SNLCS. pp. 19-22.

Weber Jr, W.J., McGinly, P.M. and Katz, L.E. 1992. Distributed reactivity model for sorption by soils and sediments. *Environmental Science and Technology* 26: 1955-1962.

Weber, J.B. 1991. Fate and behaviour of herbicides in soils. *Applied Plant Sciences* 5: 28-4.

Wong, M.H. and A.D. Bradshaw. 1982. A comparison of the toxicity of heavy metals, using root elongation of rye grass, *Lolium perenne*. *New Phytologist* 91:255-261.

Wösten, J.H.M., Ismail, A.B. and Van Wijk, A.L.M.1997. Peat subsidence and its practical implications: a case study in Malaysia. *Geoderma* 78: 25–36.

Wu, J., Laird, D.A. and Thompson, M.L. 1999. Sorption and desorption of copper on soil clay components. *Journal of Environment Quality* 28:334-338.

Xiong, Z.T., Li, Y.H. and Xu, B. 2002. Nutrition influence on copper accumulation by *Brassica pekinensis* Rupr. *Ecotoxicology and Environmental Safety* 53:200-205.

Xiong, X., Li, Y.X., Li, W., Lin., C.N., Han, W. and Yang, M. 2010. Copper content in animal manures and potential risk of soil copper pollution with animal manure use in agriculture. *Resources, Conservation and Recycling* 54: 985–990.

Xiong, Z.T., Liu, C. and Geng, B. 2006. Phytotoxic effects of copper on nitrogen metabolism and plant growth in *Brassica pekinensis* Rupr. *Ecotoxicology and Environmental Safety* 64: 273-280.

Xue, H., Nhat, P.H., Gachter, R. and Hooda, P.S. 2003. The transport of Cu and Zn from agricultural soils to surface water in a small catchment. *Advance Environmental Research* 8:69-76.

Yang, J. and K., Kuboi. 1991. Effects of Cd and Cu on the increment and assimilation of plant cells. *Acta Scientiae Circumstantiae* 11:381-388.

Yau, P.Y., Loh, C.F. and Azmil, I.A.R. 1991. Copper toxicity of clove (*Syzgium aromaticum* L. Merr. and Perry seedlings. *MARDI Research Journal* 19:49-53.

Yin, Y., C.A. Impellitri, S.J. You and H.E. Allen. 2000. The importance of organic matter distribution and extract soil:solution ratio on the desorption of heavy metals from soils. *Science of the Total Environment* 287: 107-119.

Yu, S. He, Z.L., Huang, C.Y., Chen, G.C. and Calvert, D.V. 2002. Adsorption-desoorption behaviour in copper at contaminated levels in red soils from China. *Journal of Environmental Quality* 31:1129-1136.

Yuan, G. and Lavkulich, M. 1997. Sorption behaviour of copper, zinc and cadmium in response to stimulated changes in soil properties. *Communication of Soil Science and Plant Analysis*. 28:571-587.

Zarcinas, B.A., C.I., Fauziah, M.J., Mclaughlin and G., Gozen. 2004. Heavy metals in soils and crops in Southeast Asia 1. Peninsular Malaysia. *Environmental Geochemistry and Health* 26:343-357.

Zauyah, S., B., Juliana and C.I., Fauziah. 2008. Concentration and Chemical Forms of Heavy Metals in Some Ultisols in Johore, Peninsular Malaysia. *Malaysia Journal Soil Science* 12: 113-124.

Zhou, W., Kornegay, E.T., Lindemann, M.D., Swinkels, J.W., Welten, M.K., Wong, E.A. 1994. Stimulation of growth by intravenous injection of copper in weanling pigs. *Journal of Animal Science* 72:2395–403.

Zidan, M.M.H., Amran, A.M., Shahidan, R. and Zaharudin, A. 2010. Influence of the physic-chemical properties of Selangor soil series on the distribution coefficient (K^d-value) of 226^{Ra}. *Journal of Radional Nuclear Chemistry* 285: 271-277.