ผลของปุ๋ยอินทรีย์และการเติมโพแทสเซียมไฮดรอกไซด์ที่มีผลต่อ
แคดเมียมในรูปดูดซึมได้ในดินปลูกข้าว

นายมงคลชัย อัศวดิษฐเลิศ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)

บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2552

EFFECT OF ORGANIC FERTILIZER AND POTASSIUM HYDROXIDE ADDITION ON CADMIUM BIOAVAILABILITY IN PADDY SOIL

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Environmental Management
(Interdisciplinary Program)
Graduate School
Chulalongkorn University
Academic Year 2009

Thesis Title	EFFECT OF ORGANIC FERTILIZER AND POTASSIUM HYDROXIDE ADDITION ON CADMIUM BIOAVAILABILITY IN PADDY SOIL
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Field of Study	Environmental Management
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มงคลชัย อัศวดิษฐเลิศ: ผลของปุ๋ยอินทรีย์และการเติมโพแทสเซียมไฮดรอกไซด์ที่มีผลต่อแคดเมียมในรูปดูดซึมได้ในดินปลูกข้าว. (EFFECT OF ORGANIC FERTILIZER AND POTASSIUM HYDROXIDE ADDITION ON CADMIUM BIOAVAILABILITY IN PADDY SOIL) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: อ.ดร.จันทรา ทองคำเภา, 110 หน้า.

งานวิจัยนี้ศึกษาถึงผลกระทบของปุ๋ยอินทรีย์ที่มีต่อค่า pH, Cd phytoavailability และค่าการกระจายตัวของแคดเมียมในต้นข้าว โดยทำการทดลองในกระถางทดลองและบริเวณพื้นที่ปนเปื้อน สำหรับการทดลองในพื้นที่ปนเปื้อนใช้ดินที่มีความเข้มข้นแคดเมียมสูง (มากกว่า 3 มิลลิกรัมต่อกิโลกรัมดิน) และดินที่มีความเข้มข้นแคดเมียมต่ำ (น้อยกว่า 0.5 มิลลิกรัมต่อกิโลกรัมดิน) ส่วนการทดลองในกระถาง ใช้ดินที่มีความเข้มข้นแคดเมียมสูง (มากกว่า 60 มิลลิกรัมต่อกิโลกรัมดิน) ในการทดลองปลูกในกระถาง ใช้ดิน 5 กิโลกรัม/กระถาง และเติมสารละลายโพแทสเซียมไฮดรอกไซด์ความเข้มข้น 1 โมลต่อลิตร ปริมาตร 80 และ 240 มิลลิลิตร และใส่ปุ๋ยอินทรีย์แตกต่างกันสี่ระดับ คือ 0 (ชุดควบคุม), 10, 20 และ100 กรัม/กระถาง ดินที่เติมสารละลายโพแทสเซียมไฮดรอกไซด์มีมีผลต่อการเพิ่ม pH ของดิน และพบว่าในช่วง vegetative stage ต้นข้าวมีอาการแคระแกร็นและตายในที่สุด ผลการทดลองแสดงให้เห็นผลรวมของแคดเมียมในรูปที่ละลายได้และรูปที่แลกเปลี่ยนไอออนได้ (F1) และแคดเมียมในรูปรีดิวซ์ได้ (F2) จะลดลงเมื่อเติมสารละลายโพแทสเซียมไฮดรอกไซด์เพิ่มมากขึ้น แต่ในส่วนของการเติมปุ๋ยอินทรีย์พบว่า แคดเมียมที่ถูกออกซิไดส์ได้ (F3) มีค่าเพิ่มขึ้น และสัดส่วนของF1ลดลง อีกทั้งยังพบว่ามีการเพิ่มขึ้นของน้ำหนักมวลรวมแห้งเมื่อใส่ปุ๋ยอินทรีย์เพิ่มขึ้นด้วย ลำดับความเข้มข้นของแคดเมียมที่พบในส่วนต่างๆของต้นพืชมีดังนี้ ราก > ลำต้น > เมล็ดข้าว การลดลงของแคดเมียมเมื่อใส่ปุ๋ยในต้นข้าวเป็นการลดลงอย่างไม่มีนัยสำคัญ ในส่วนของการทดลองในพื้นที่ปนเปื้อนการใส่ปุ๋ยเพิ่มขึ้นไม่มีผลต่อการเพิ่มขึ้นของ F3 อย่างมีนัยสำคัญ แต่กระนั้นพบว่าแคดเมียมในเมล็ดข้าวมีการลดลงทั้งในแปลงที่มีการปนเปื้อนแคดเมียมสูงและต่ำ อย่างไรก็ตามไม่สามารถสรุปได้ชัดว่าการลดลงของแคดเมียมในเมล็ดข้าวและการเพิ่มขึ้นของ F3 นี้ เป็นผลมาจากในปุ๋ยอินทรีย์ที่เติมไปเท่านั้น เนื่องจากมีหลายปัจจัยในพื้นที่ศึกษาที่ไม่สามารถควบคุมได้ สำหรับผลผลิตของเมล็ดข้าวจากการทดลองในสี่พื้นที่พบว่ามีความแตกต่างอย่างมีนัยสำคัญ โดยพบว่ามีเพียงแปลงที่ปนเปื้อนแคดเมียมต่ำแปลงเดียวเท่านั้นที่ชุดควบคุมที่จะให้ผลผลิตสูงเมื่อเติมปุ๋ยอินทรีย์

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต มงคลชัย อัศวดิษฐเลิศ

ปีการศึกษา : 2552 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก

5187558820 : MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS : CADMIUM /ZINC/ ORGANIC FERTILIZER/ IMMOBILIZATION/ RICE PLANT

MONGKOLCHAI ASSAWADITHALERD: EFFECT OF ORGANIC FERTILIZER AND POTASSIUM HYDROXIDE ADDITION ON CADMIUM BIOAVAILABILITY IN PADDY SOIL. THESIS ADVISOR: CHANTRA TONGCUMPOU, Ph.D., 110 pp.

In this work the effects of organic fertilizer on the pH, Cd phytoavailability and Cd distribution in rice plants was examined in a pot experiment and field experiments using Cd contaminated soil at high concentration (> 60 mg /kg soil) for the pot experiment; and for the field experiment both high (> 3 mg /kg soil) and low (< 0.5 mg/kg) Cd concentrations were selected for the evaluation. For pot experiment, the 5 kg soil/pot was treated with 1 Mol/L KOH addition with 80 and 240 mL and organic fertilizer addition at 4 levels; 0 (control), 10, 20, and 100 g/pot (5 kg soil). For KOH addition, increasing pH was found to be an obvious effect which resulted to the rice during the vegetative stage became dwarf and died finally. . The result showed that the combination of the soluble and exchangeable Cd fraction (F1) and the reducible Cd fraction (F2) was decreasing when KOH addition increased. For the organic fertilizer addition, the result showed that addition of organic fertilizer increased oxidizable Cd fraction (F3) and decreased the soluble and exchangeable Cd fraction (F1). There was an increase of dry matter yield with increasing organic fertilizer addition. Cd concentration in plant parts was found in root > stem > grain. No such significant reduction in rice plant was seen for Cd by organic fertilizer addition. For field experiment, despite the fact that the organic fertilizer addition was not shown an effect on the increasing F3 significantly, Cd in rice grain were found decreasing for both plots of high and low Cd contaminations. However, it may not be confident to conclude that the increasing is occurred only form organic fertilizer addition since there were several factors in the field study were out of control. Productivity of rice grain from the four filed sites experiment were found insignificantly different, only one control plot with low concentration that show the higher production from organic fertilizer addition.

Field of Study : Environmental Management Student's Signature Mongkoldhai. A.
Academic Year : 2009 Advisor's Signature Ch T.

ACKNOWLEDGEMENTS

I would like to express my deep sincere gratitude to my thesis advisor, Dr.Chantra Tongcumpou for her valuable suggestion, assistance and strong encouragement including her time throughout the thesis work.

I also extend my warm and sincere thanks to the thesis committee chairman, Assistant Prof Dr. Ekawan Luepromchai, and the thesis committee members, Dr. Pantawat Sampanpanish and Dr. Nyein Nyein Aung for their detailed review, encouragement, helpful suggestions, and constructive criticism.

Special respect and thanks are also extended Mr. Meechai Siangliw for his great help in the pot and also field experiment throughout the studies. Furthermore, I would like to thank sincerely to Mr. Akechai Sankumgon, Dr.Chulalak Chankul and Ms.Pririya Rampai for supporting all helps in field and sample preparation in laboratory including map creation by GIS. The author is thankful to Ms.Waleeporn Sripenprapa for the assistance and guidance with the GF-AAS and also Assistant Prof Dr.Krisanavej Thongtanasak to give compost obtained from Nonthaburi Municipality for using in pot experiment.

Moreover, I would like to express gratitude to all staffs, especially, librarian of NCE-EHWM (Miss Soawaros Mornsuparp) to provide more helpful for searching knowledge and friends at international Postgraduate Programs in the National Center of Excellence for Environmental and Hazardous Waste Management (NCE-EHWM). Especially my colleague, Miss Nina Siebers was of great help in difficult times, valuable hints and English grammar correction. In addition, I would like to thank the NCE-EHWM for its financial support throughout this program, and for giving me the opportunity for making the experiences during the last two years.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BCR	Community Bureau of Reference
CEC	Cation Exchange Capacity
F1	Soluble and exchangeable fraction
F2	Reducible fraction
F3	Oxidizable fraction
F-AAS	Flame Atomic Absorption Spectrometer
FAS	Ferrous ammonium sulfate
GF-AAS	Graphite Furnace Atomic Absorption Spectrometer
GIS	Geographic Information System
HCS	High Concentration Site
LCS	Low Concentration Site
N	Normality
NCE-EHWM	National Center of Excellence for Environmental and Hazardous Waste Management
SOM	Soil Organic Matter
SM&T	Standard, Measurement and Testing Programme of the European Union

CHAPTER I
INTRODUCTION

1.1 General Statement

Natural geochemical processes and anthropogenic activities are two major causes of releasing hazardous substances such as heavy metals and other toxic substances to the environment. Cadmium (Cd) can mainly be found in the earth's crust and is released into rivers through weathering of rocks and into the air through forest fires and volcano eruptions. Despite natural processes, Cd is also released through human activities. Cd naturally coexists with zinc (Zn); thus, it is a by-product of the Zn mining industry. Cd enters the environment mainly through the ground because it is found in manures and pesticides. Of all non-essential heavy metals, Cd is perhaps the metal which has attracted most attention in soil science and plant nutrition due to its potential toxicity to man and relative mobility in the soil plant system. The management of Cd in soil plant systems is difficult because of its very variable relationship between accumulation in soil and translocation to plants and the food chain.

Cd is a by-product of the Zn industry; therefore, Cd can be found in increasing amounts in the soil around those industries. Cd contamination caused by mining activities over three decades has received considerable critical attention in the Mae-Sot district, Tak province, Thailand (Pensiri Akkajit, 2008). Cd concentration in paddy soil has become an environmental issue since 2003 because Cd was uptaken by the rice grown in this area. The paddy fields are receiving irrigation water from the two creeks (Mae Tao and Mae Ku) passing the Zn mining area and were found to contain markedly elevated Cd and Zn levels. Cd in rice grains was determined for 524 fields and was found to be in the range of 0.05 to 7.7 mg/kg. Over 90% of the rice grain samples collected contained Cd at concentrations exceeding the Codex Committee on Food Additives and Contaminants (CCFAC) Maximum Permissible Level for rice grains of 0.2 mg Cd/kg (Simmons et al., 2005)

Thailand is the leader of rice exporting nation, which produces the famous Jasmine rice cultivar; therefore, crop production in Cd contaminated areas has become an issue of concern due to elevated Cd concentrations found in rice plants, which possesses a health risk to humans and the environment. An elevated consumption of Cd can cause kidney damage and is linked to renal dysfunction. Other diseases associated with Cd exposure are pulmonary emphysema and the notorious Itai–Itai disease (Yeung and Hsu, 2005). Exposure of humans to Cd is via the food chain and drinks. An increase in the soil Cd content generally results in an increase of the plant uptake of Cd although soil properties and types of plants grown on soil are considered as crucial factors influencing Cd accumulation (Swaddiwudhipong et al., 2007).

Several approaches have been introduced to decrease the Cd bioavailability in contaminated soils including chemical and organic soil amendments. In this study organic fertilizer or compost amendments are introduced to be natural material application based on the theory that organic matter in the fertilizer may bind to the Cd and hence decreases the mobility of Cd. At the same time, the organic fertilizer can release macronutrients and micronutrients resulting in a soil quality improvement such as the water holding capacity, buffering soil pH, and increasing of the soil CEC (Havlin et al., 1999). In the agricultural sector, usage of organic fertilizers produced from local materials and agricultural wastes is sustainable and can maintain soil's quality in the long run.

1.2 Objectives

There are two main objectives of this study:

1. To study the effects of organic fertilizer (compost), potassium hydroxide, and the combination of potassium hydroxide and organic fertilizer addition to the soil on Cd in the rice biomass.
2. To determine the Cd soil fractions in order to investigate the effects of the amendment addition as proposed in the first objective on the Cd forms in soil.

1.3 Hypothesis

The addition of organic fertilizers and potassium hydroxide can immobilize cadmium in the soil phase and reduce the cadmium bioavailability by *Oryza sativa* L. (Khoa Dawk Mali 105)

1.4 Scopes of the study

The Jasmine rice 105 cultivar (Khoa Dawk Mali 105) is a photoperiod sensitive cultivar, which was selected in this study to conduct a pot experiment and a field study.

1.4.1 Pot experiment

1. A pot experiment was carried out at the Kasetsart University, Kamphaengsaen Campus, Nakornpatom.
2. Cd contaminated soil was used with an initial Cd concentration of >70 mg Cd/kg soil. The soil for the pot experiment was collected from Cd contaminated areas with high Cd contamination in the Mae-Sot district. Each pot contained 5 kg dry soil.
3. A pot study was performed studying potassium hydroxide, organic fertilizer, and a combination of potassium hydroxide and organic fertilizer addition.
4. The Organic fertilizers used in the pot study was a commercial compost obtained from Nonthaburi municipality and an organic fertilizer prepared by composting using PD1 (Pattana-tee-din1) as inoculums.
5. The amounts of organic fertilizer added were 10, 25, and 100 g/pot. Concentrations of 1 Mol/L potassium hydroxide solution added were 80 and 240 mL/pot.
6. The samples were collected at four different stages, namely after amendment addition, after 60 days (vegetative stage), 90 days (panicle formation stage), and 120 days (maturity stage).

1.4.2 Selected plots at a contaminated site

1. The organic fertilizer was applied to four selected plots in the Mae-Sot District, Tak Province, exhibiting a low and high Cd contamination.
2. The organic fertilizer used in this study was prepared by composting leaves, branches, and biomass residues mixed with cow manure using PD1 (Pattana-

tee-din1) as inoculums. The organic fertilizer was applied at a concentration of 500 kg/rai

3. The samples were collected at five different stages, namely before organic fertilizer addition (background), after organic fertilizer addition and before transplanting of the rice seedlings, after 60 days (vegetative stage), 90 days (panicle formation stage), and 120 days (maturity stage).

1.4.3 Samples and analysis

Same sample analysis procedures were applied for samples collected from the pot as well as from the field study.

1. Soil properties were analyzed for:
   1.1 Soil pH by using a pH meter.
   1.2 Soil organic matter (OM) by using a wet digestion method according to the Walkley – Black method.
   1.3 Oxidation Reduction Potential (ORP) by using an Oxidation Reduction Potential meter.
2. Metal Analysis
   2.1 The two metals of interest were Cd and Zn)
   2.2 The Cd and Zn concentrations were analyzed by Atomic Absorption Spectrometer (AAS)
   2.3 The soil samples were subjected to both a total digestion and sequential extraction procedure according to the EPA 3052 method and BCR sequential extraction procedure proposed by the Standards, Measurements and Testing programme of the European Union (SM&T), respectively.
   2.4 The rice plant parts, namely stems with leaves, panicles, and grains were digested by using a wet ashing method with HNO_3 and H_2O_2 as reagents. Root samples were digested by wet ashing with HNO3 and HCl.

CHAPTER II
THEORETICAL BACKGROUND AND LITERATURE REVIEW

This study focused on the Cd bioavailability to rice plants; therefore, specific principles related to this aspect are

- Forms and chemical speciation of heavy metals
- Bioavailability and translocation in plants
- Interactions between plant roots, soil solution, and soil
- Factors affecting Cd mobilization and availability
- Cultivation of rice

2.1 Forms and chemical speciation of heavy metals

The mobilization and bioavailability of heavy metals always depends on the form or chemical species (Adriano, 2001). In soils, solubility equilibria may change significantly within a few centimeters (even millimeters) at both horizontal and vertical soil gradients (Kabata Pendias and Pendias, 2001). There are many chemical processes related to fate of heavy metals namely adsorption, complexation, ion exchange, and precipitation (Adriano et al., 2004).

Chemical extraction is applied to access operationally defined metal fractions, which can be related to chemical species as well as to the potential mobility, bioavailability, or ecotoxicity (Joszef et al., 2004). Sequential extraction schemes use suitable reagents which are applied in a given order to the sample; the number of stages and the choice of the specific reagent used in each scheme is dependent on the goals and on the physical characteristics of the target sample (Kennedy et al., 1997). The choice of a suitable extractant should be strictly correlated with: (a) the nature of the metal, (b) the chemical form of the metal, (c) the matrix from which the compounds are extracted, and (d) the analytical techniques available in the laboratory for the final determination.

In all schemes, extractants are applied with increasing reactivity so that the successive fractions obtained correspond to metal forms with lesser mobility (Figure 2.1). Extractants commonly used in sequential extraction schemes fall generally within the following groups: unbuffered salts, weak acids, reducing agents, oxidizing agents, and strong acids.

Table 2.1 The BCR three-stage sequential extraction scheme (Tokalioglu et al., 2003)

Step	Reagents	Fractions/Forms
1	Acetic acid: CH_3COOH (0.11 Mol/L), pH 2.85	Exchangeable, water and acid soluble (e.g., carbonates)
2	Hydroxylammonium chloride: $NH_2OH.HCl$ (0.1 Mol/L) at pH 2	Reducible (e.g., iron/manganese oxides)
3	Hydrogen peroxide: H_2O_2 (8.8 Mol/L), followed by ammonium acetate: CH_3COONH_4 (1.0 Mol/L) at pH 2	Oxidizable (e.g., organic substance and sulphides)
4 Residual	Aqua regia: $3HCl + HNO_3$	Remaining, non-silicate bound metals

*The residual material is not included in the BCR protocol.

The three stage sequential extraction procedure proposed in Table 2.1, a protocol proposed by a European working group coordinated and supported by the Community Bureau of Reference (BCR), was used to investigate all three fractions in this study. The determination of the residual fraction (Step 4) is not included in the BCR extraction procedure protocol (Davidson et al., 1998; Ipolyi et al., 2002; Tokaliolu et al., 2003). The residual fraction can be determined by many different approaches depending on the type of soil; for example, siliceous soil should be digested by hydrofluoric acid, hydrochloric acid, and nitric acid following the procedure of the EPA 3052.

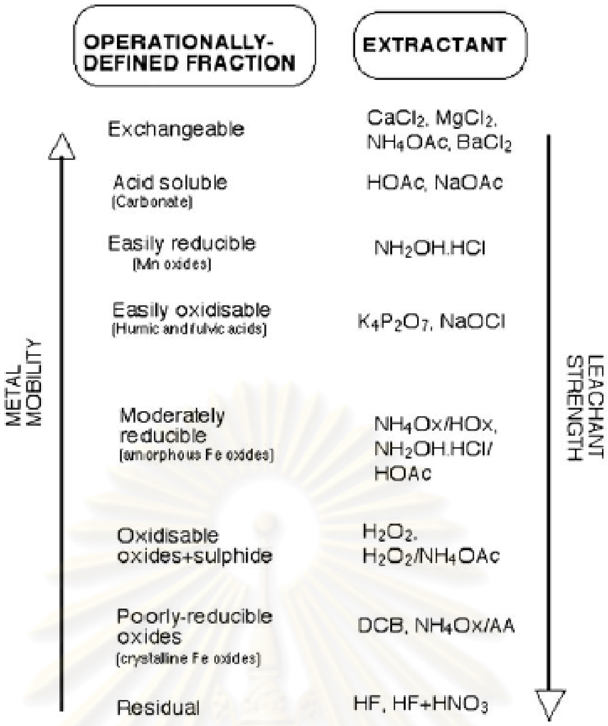

Figure 2.1 Relationship between metal mobility in the different operationally defined phases and leachant strength of common chemical reagents used for sequential extraction (Filgueiras et al., 2004)

Three steps of BCR extraction can be defined as exchangeable fraction, Reducible fraction and oxidizable fraction. The exchangeable fraction includes weakly adsorbed metals retained on the solid surface by relatively weak electrostatic interaction, metals that can be released by ion-exchange processes and metals that can be coprecipitated with carbonates present in the solid phase. Generally, heavy metals in the exchangeable and acid soluble fraction are considered readily and potentially bioavailable, while the reducible and oxidizable fractions are relatively stable under normal soil conditions (Wong et al., 2002**).** In the BCR2 extraction step, Cd associated to the iron-manganese oxide fractions is extracted, which is the well known 'sink' of the surface environment for heavy metals. Reduction of Fe (III) and Mn (IV) under anoxic conditions and their subsequent dissolution could release adsorbed trace metals. Hydroxylamine hydrochloride in nitric acid medium is a widely used reagent to extract the easily reducible fraction. The Cd associated to the exchangeable (BCR1) and reducible (BCR2) fraction in anoxic condition is mobile and available for plant uptake, while those in the latter stages of the extraction schemes are less available to plants. The organic fraction released in the oxidizable step is not considered very mobile or available since it is thought to be associated with stable high molecular weight humic substances that release small amounts of metals in a slow manner. Metallic pollutants associated with oxidizable phases are assumed to remain in the soil for longer periods but may be mobilized by decomposition processes.

2.2 Bioavailability and translocation in plants

The behavior of the elements in the environment cannot be predicted on the basis of their total concentration because not all metals are labile or bioavailable (Gobran et al., 2001) due to complex distribution patterns among various chemical species of the solid phase. The total metal content of a soil is distributed among all possible chemical forms (speciation) in the solid, liquid or the biotic phase (Vig et al., 2003). The assessment of environmental risks requires not only the determination of total amounts of heavy metals in the soil but also the heavy metal concentration in each fraction, i.e., the availability of the heavy metals. A widely used method for the identification and evaluation of the availability of heavy metals in soils is the leaching from soils by means of chemical extractants.

Different definitions of bioavailability (Adriano, 2001; Semple et al., 2004) defines “availability” and “bioavailability” as

- The rate and extent at which a chemical is released from a medium of concern.
- The bioavailability of the chemical to living receptors (e.g., plant roots) through direct contact or uptake.

Bioavailability of heavy metals depends greatly on the characteristics of the particle surface, on the kind of strength of the bond and on the properties of the solution in contact with the solid samples. Once the ions have been absorbed through the roots or leaves and have been transported to the xylem vessels, there is the possibility of movement throughout the whole plant. The rate and extent of movement within plants depends on the type of metal, the plant organ, and the age of the plant (Alloway, 1995).

2.3 Interactions of plant roots, soil solution and soil

The rhizosphere is generally considered to be a narrow zone of about 1-2 mm between the bulk soil and the plant roots, where the root exudates stimulate or inhibit microbial populations and their activities. The rhizosphere controls the uptake of nutrients as well as toxic compounds by plants, plant growth, and the microbial activity. The rhizosphere soil differs from the bulk soil in its physical, chemical, and biological characteristics, which affects the trace element distribution and the overall bioavailability to plants.

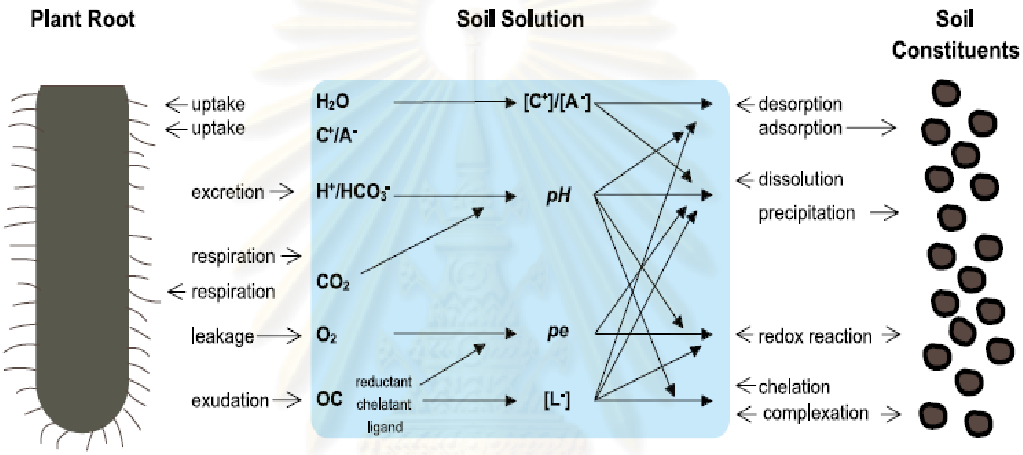

Figure 2.2 Schematic chart of the rhizosphere showing the various exudates and their influence on abiotic factors and reactions in the soil – solution interface. OC = organic carbon; C^+ = cation; A^- = anion; L^- = ligand; pe = redox potential. (Adraino et al., 2004).

In the rhizosphere soil, water and nutrients dynamically move and are concentrated around the roots as show in Figure 2.2. The water potential regime in the rhizosphere soil is generally lower than in the bulk soil. The redox potential is more negative in the rhizosphere soil than in the bulk soil, due to the higher oxygen consumption as part of the respiration performed by the plant roots and microorganisms. Plant roots and root-induced chemical changes in the rhizosphere strongly affect the bioavailability of trace elements. Firstly, root-induced changes in the ionic equilibria influence the bioavailability of trace elements. The differential rates of plant uptake of water and ions in the soil solution result in a depletion or an accumulation of the ions in the rhizosphere. In general, trace elements present at low concentrations in the soil solution are most likely to be depleted as a consequence of plant uptake. Secondly, root-induced changes in the pH and redox potential in the rhizosphere affect the dynamics of trace elements, either through changes of speciation or through dissolution of the trace element bearing mineral phases (Gobran et. al., 2000).

The root-induced changes in pH is primarily a consequence of both the excretion of protons (Mclaren and Cameron, 1996) and the differential rates of uptake of cations and anions by plants, which are compensated by a release of protons or hydroxyl/bicarbonate ions in the rhizosphere. Plant roots are likely to alter the speciation of these elements. Many trace element carbonates and oxides are soluble under acidic or reducing conditions, which are present in the rhizosphere. Finally, root exudates as well as microbe-induced organic compounds (phytosiderophores and organic acids) containing complex substances tend to increase the solubility and thus the bioavailability of trace elements in soils. These released organic molecules are prime sources of energy for rhizosphere microorganisms. Some exudates contain carboxylic anions such as citrate, oxalate or malate, and phytosiderophores exhibiting strong complexation properties with respect to a whole range of trace elements (Fe, Cd, Cu, and Zn) (Gobran et. al., 2000).

2.4 Factors affecting the Cd mobilization and availability

There are many factors that affect metal mobilization and immobilization that are related to bioavailability. Important factors for this study are comprised of:

- pH
- ORP
- Zinc
- Organic matter

2.4.1 pH

Soil pH is the major factor determining the availability of Cd in the soil because it affects metal speciation with adsorption and desorption mechanisms on solid surfaces as well as in the soil solution and the solubility of metal hydroxide minerals. Cd uptake is inversely related to soil pH (Alloway, 1995). Under natural conditions, the soil pH ranges most often between 5 and 7, except where there is a high reductive state in waterlogged soil (Kabata Pendias and Pendias, 2001). Soil pH is also negatively correlated to the Cd content in rice. Total Cd uptake and shoot uptake increased with increasing redox potential and a decrease in pH (Adriano, 2001).

Precipitation as metal hydroxides or carbonates is considered to be one of the mechanisms for the immobilization of metals, such as Pb, Zn, and Cd by liming materials (Pierzynski and Schwab, 1993). The formation of the new solid phase (i.e., precipitates) occurs when the ionic product in the solution exceeds the solubility product of that phase. In normal soils, precipitation of metals is unlikely, but in highly metal contaminated soils, this process can play a major role in the immobilization of metals, especially under alkaline soil pH. (Bolan et al., 2003b)

2.4.2 Oxidation-reduction potential (ORP or Eh)

Oxidation-reduction processes are expected to play a major role in the mobilization and immobilization processes of trace elements that can occur under various redox potentials of the soil (Selim and Kingery, 2001). Changes in the oxidation state of the metals associated with the oxides can greatly affect their solubility and mobility in soil and aqueous environments (Lee, 2006). Under flooded conditions a greatly reduced solubility of Cd could be observed. This behavior of Cd is due to the formation of CdS solid phase at a low redox potential. Under low Eh and high pH conditions, the adsorption of Cd by amorphous oxyhydroxides of Fe and Mn may also be important (Adriano, 2001).

2.4.3 Zinc

Zn belongs to group IIB together with Cd and Hg (mercury), which potentially are the most hazardous elements for the biosphere found in the periodic table. Cd is similar in many aspects to Zn. The close association of Cd and Zn in geological deposits and the chemical similarity of the two elements carry over into biological systems. Cd has no known biological function, but Zn is an essential element. Under conditions of Zn adequacy other mechanisms may affect Cd uptake and translocation in plants including competition between Cd and Zn at uptake sites on the root-cell plasma membrane surface, loading of Cd into xylem elements for the transportation from the roots to the leaves, and symplasmic transport of Cd to, and loading of Cd into, phloem elements for movement into phloem sink tissues including reproductive organs, growing points and newly forming roots (Adriano, 2001).

2.4.4 Organic matter

The major portion of the organic matter (OM) in most soils results from biological decay of biota residues. The end products of this degradation are humic substances, organic acids of low-molecular and high-molecular weights, carbohydrates, proteins, peptides, amino acids, lipids, waxes, polycyclic aromatic hydrocarbons, and lignin fragments. In addition, the excretion products of roots, composed of a wide variety of simple organic acids, are present in soils (Essington, 2003).

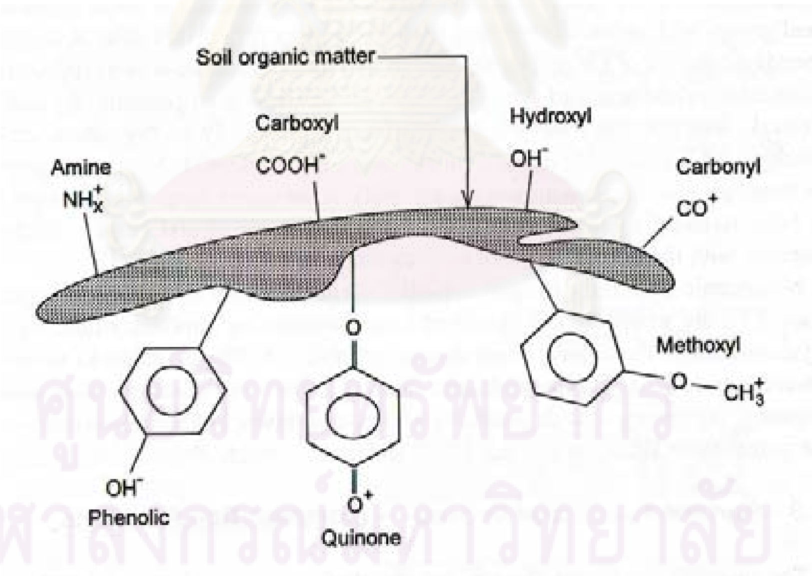

Figure 2.3 Sketch of soil organic matter (SOM) showing various kinds of functional groups associated with soil components (Yong, 2002).

Soil organic matter (SOM) is composed of polycyclic or aromatic rings. As shown in Figure 2., carbon and nitrogen combined with oxygen and/or hydrogen form the various types of surface functional groups. The most common functional groups are hydroxyl groups, carboxyl groups, phenolic groups, and amines. They can protonate or deprotonate depending on the aqueous environment pH, i.e., they develop positive or negative charges depending on the pH of the soil. The carboxyl groups are the major contributors to the acidic properties of the soil organics (Yong, 2002).

The organic components of soil constituents have a high affinity for metal cations because of the presence of ligands or groups that can chelate metals (Harter and Naidu, 1995). With increasing pH, the carboxyl, phenolic, alcoholic and carbonyl functional groups in SOM dissociate and thereby increase the affinity of ligand ions for metal cations. The general order of affinity for metal cations complexed by organic matter follows the order $Cu^{2+} > Cd^{2+} > Fe^{2+} > Pb^{2+} > Ni^{2+} > Co^{2+} > Mn^{2+} > Zn^{2+}$ (Adriano, 2001).

OM affects the transportation (and subsequent leaching) and accumulation of metal ions present in soils and waters as chelates possessing different stabilities and thus the supply of these ions to plant roots. OM can absorb metal ions by ion exchange mechanism rendering them less mobile and therefore less bioavailable. The sorption ability of OM for Cd is predominantly defined through its cation exchange capacity (CEC) rather than chelating ability. In addition to CEC, soil humus has also a chelating ability, and some metals have a tendency to combine with certain chelating groups. Metal-fulvic acid complexes with lower stability constants usually are more readily soluble and thus more available to plant roots.

2.5 Rice and cultivation

This study focused on the rice cultivar Jasmine Rice 105 or Khao Dawk Mali 105, which is a photoperiod sensitive cultivar; therefore, the growth length depends on the light but normally is about 120 days. The recommended cultivation areas in Thailand are the North and North-East with a productivity of about 362 kg/Rai. Prominent properties are a good aroma and it is drought, saline, and acid resistant. This formation can be divided as two parts which are as follows:

- Rice growth stages
- Cultivation

2.5.1 Rice growth stages

Rice seeds are capable to germinate under water and the coleoptile of the rice embryo grows more rapidly and more extensively under water than in air. The seedlings should be transplanted approximately one month after sowing in the nursery. At this stage the seedlings have four to five leaves. Only strong seedlings are transplanted. The seedlings must be transplanted into a very wet soil and planted in straight rows with proper spacing between them. Usually, a distinction is made between the four growth stages of rice, which are presented in Figure 2..

Figure 2.4 Sketch of the rice morphology in each stage of rice growth (The Food and Agriculture Organization of the United Nations, 1989)

The details and definitions of the rice growth stages and drain development are described in the following paragraphs.

Nursery stage: from sowing to transplanting; the duration is approximately one month.

Vegetative stage: from transplanting to panicle initiation; the duration varies from 1 to 3 months. The vegetative stage includes the tillering, meaning that several stems develop on one plant. If the rice is sown directly (broadcast), the two combined stages are called the vegetative stage.

Mid season or reproductive stage: from panicle initiation to flowering; the duration is approximately one month. This stage includes stem elongation, panicle extension, and flowering. Late tillers may die.

Late season or ripening stage: from flowering to full maturity; the duration is approximately one month. This stage includes grain growth.

When rice growth reach the late season or ripening stage, the development of the individual rice grains from anthesis through grain dry down starts. Each stage of development is illustrated in Figure 2. and described in the following information.

Anthesis: One or more florets on the panicles of the main stem has been formed.

Caryopsis expansion: At least one caryopsis on the main stem panicle is elongating to the end of the hull.

Grain filling: Starch is synthesized in this stage.

End of grain filling: At least one grain on the main stem panicle has a yellow hull.

Grain dry down: All grains have brown a hull.

Figure 2.5 The morphology of the rice grain from anthesis through grain dry down (Adapted from Counce et al., 2005).

In paddy soils, soil solution pH alters towards near neutral as the system moves from oxidizing to reducing conditions, which reduces Cd phytoavailability. However, drainage of fields at the critical grainfill stage in order to optimize yields and facilitate ease of harvesting decreases the soil pH to the antecedent condition and increases the Cd phytoavailablity to rice plants (Chaney et al., 1996).

2.5.2 Cultivation

Many steps have to be taken into account when growing rice such as weeding, fertilization, and pest control. Weeds prevent rice from growing and tillering well. Weeding usually starts two weeks after transplanting and continues as necessary throughout the growing season. All plants need nutrients for growth. For rice cultivation, fertilizers are usually applied just before transplanting, one month after transplanting, and one month before flowering. Moreover, pest control is needed because rats, birds, and insects often do much damage to the rice crop.

The tillage system and the irrigation system also affect the fate and bioavailability of Cd in soil. Tillage may impact the pH, organic matter, and nutrient stratification in the soil profile as well as the microclimate, the root distribution, and crop growth dynamics. These effects may influence Cd uptake by crops. Deep tillage may have some potential for reducing the uptake of Cd by crops. This technique could be effective in conditions where the surface soil has been enriched in Cd (McLaughlin and Singh, 1999). Irrigation water quality can have a marked effect on crop Cd concentrations, largely through addition of elements in the applied water. Ions like chloride, bicarbonate, or sulfate present in the irrigation water affect the availability and immobilization of Cd as well (Brown et al., 2002).

2.6 Literature review

Several studies have been conducted to determine the Cd amount in the biomass of many kinds of plants including edible plants. The uptake of Cd by crops possesses a risk for the health of humans. Biosolid, manure, and compost addition have also been studied with respect to heavy metal stabilization in soil and a possible reduction of the bioavailability. In addition, the effect of lime addition on immobilization and phytoavailability was studied as well.

Bolan et al. (2003a) studied the effects of biosolid compost on the uptake of Cd from Manawatu soil using mustard plants (*Brassica juncea* L.). Increasing addition of Cd increased the Cd concentration in plants, resulting in a decreased plant growth at high levels of Cd. Addition of biosolid compost was effective in reducing the phytotoxicity of Cd as indicated by a decrease in the concentration of NH_4OAc extractable-Cd and soil solution-Cd. The solid phase fractionation study indicated that the addition of biosolid compost decreased the concentration of the soluble and exchangeable Cd fraction but increased the concentration of organic-bound Cd fraction in soil.

Pichtel and Bradway (2008) studied the effects of organic amendments on Pb, Cd, and Zn uptake by conventional crops namely spinach, cabbage, and a grass–legume mix. Both greenhouse and field conditions were studied. For greenhouse experiments, soil samples were obtained from slag and bag house dust from abandoned steel tailing disposal facility located in Western Europe. Pots were treated with composted peat (CP) by topdressing and mixing. The results indicated that composted peat in soil and the initial Cd concentration affected the uptake of Cd by plant biomass. On the field study, plots measuring were conducted by slag material with topdressing treatments to plots included farmyard manure (FYM) and CP FYM which provides more Cd stabilization for spinach and the grass–legume mix. The Cd concentration found in the biomass obtained by the field experiment with CP treatment is lower than for the greenhouse experiment because of contact with salt spray, excessive soil drainage, cooler temperatures, and other uncontrolled environmental variables the field was exposed.

Hanč et al. (2008) studied the effect of compost and poultry manure on the bioavailability of Cd and copper and their uptake by oat biomass. Poultry manure and compost application decreased the Cd uptake 3.5 times (1.7 μg per pot compared to the control), which was the lowest uptake obtained during three years. It was caused by the low Cd content in soil. It can be claimed that an application of high-quality organic matter into soil decreases Cd uptake by aboveground plant biomass. It is possible that Cd remained in the roots and was not translocated into the shoots. Roots posses a significant cation exchange capacity and this may be a part of the mechanism controlling the movement of ions through the outer part of the root to the plasmalemma, where active absorption occurs.

Bolan et al. (2003b) studied the potassium hydroxide and calcium hydroxide addition to two different soils. This resulted in an increase of Cd uptake by plants. There was no direct evidence for lime-induced precipitation of Cd as $CdCO_3$ or $Cd(OH)_2$, but it was shown that there is a significant correlation between extractable Cd concentration of extractable form and soil solution. Cd in soils can be immobilized by increasing the soil pH through addition of liming materials. Reduction of the Cd uptake is caused by an increased Cd^{2+} adsorption caused by pH induced increase of the negative surface charge of the soil. Increasing addition of Cd enhanced Cd concentration in plants, resulting in decreased plant growth (i.e., phytotoxicity). Although addition of $Ca(OH)_2$ effectively reduced Cd phytotoxicity, the Cd uptake increased at the highest level of $Ca(OH)_2$, probably due to decreased Cd^{2+} adsorption resulting from increased Ca^{2+} competition.

There are many procedures for heavy metal immobilization in soil including the addition of organic materials, as well as chemicals such as lime and sulphate.

Walker et al. (2004) studied the effects of manure and compost on soil pH, heavy metal availability, and growth of *Chenopodium album* L. in a soil contaminated by pyritic mine waste, which is a sulphide-rich waste. However, the decrease of soil pH during the experiment was only slightly observable in manure treated soil. Mineralization of the labile OM in the fresh cow manure may have altered the redox state of the soil to less oxidizing conditions; thus, minimizing the oxidation of sulphide to sulphate and the consequence of this is soil acidification. The effects of compost and manure on soil pH seemed to be the main determinants of Zn and Mn availability and uptake, so the pH effect was greater than that of metal complex formation by soluble OM. The effect of the compost with respect to metal availability was limited in this soil due to its inability to prevent acidification.

Lee et al., (2004) studied the effects of chemical amendments on the concentration of Cd and Pb in long-term contaminated soils. The application of calcium carbonate (CA), calcium carbonate mixed with Zn oxide (CA + ZN), or calcium carbonate mixed with compost (CA + CO) significantly reduced the grain and leaf Cd concentration of the wheat species. Due to the lower concentration of metals and higher contents of organic carbon in clayey soils compared with sandy soils, higher amounts of metals were adsorbed on organic carbon or clay particles in clayey soils. The addition of compost significantly reduced the Cd concentration in the husk of wheat grown in the sandy soil.

Rice is a staple food in Asia; therefore, heavy metal contamination of crops is an important issue of concern. Several researches studied the immobilization of heavy metals in soil. Rice was also reported to play important role for Cd phytoextraction.

Murakami et al. (2009) studied the phytoextraction of Cd using Indica rice cultivars capable of accumulating high levels of Cd. Phytoextraction with Indica rice reduced the total soil Cd content by 38% and reduced the grain Cd content in subsequently grown Japonica food rice by 47% without decreasing the yield. The results suggest that phytoextraction with Chokoukoku soil can remove Cd from paddy fields polluted with low to moderate levels of Cd and reduce the grain Cd concentration of Japonica food rice cultivars to below the Codex standard within a reasonable time frame.

Because of the importance of food requirements and food trading, heavy metals in rice grains are of great concern. Thus, organic material amendments such as biosolids and manure were studied. They were applied to reduce the bioavailability of Cd to rice plants, especially to the rice grain.

Khai et al. (2008) studied the effects of biosolid application on soil chemical properties in peri-urban agricultural systems. When comparing the six different treatments of composted manure and chicken manure application, the addition of biosolids had a significant positive effect on organic carbon and total nitrogen. However, The application of biosolids increased the EDTA-extractable fraction of Cd, Cu, and Zn, while no effect on NH_4NO_3-extractable fractions of these elements was observed. The addition of biosolids in the form of chicken manure and composted manure also increased the soil concentration of electroconductivity. The total concentrations of Zn and Cu (for the Vinh Phuc site) and potential dissolved Cd, Cu, and Zn were significantly higher in soils treated with biosolids, whereas the total concentrations of Cd and Pb were not different from the control. This was probably due to the short term nature of the biosolid application and the relatively low concentrations of these trace metals in the biosolids.

Metal speciation and factors affecting metal availability have been studied in paddy field simulations under flooded conditions. Flooded soil has a negative redox potential meaning that reducing conditions prevail, which is different from drained paddy soil. Oxygen and water play an important role for the redox condition (Sparks, 1995). Due to the different conditions, the interaction of ions in soil and soil solution is changed, which affects the availability.

Kashem and Singh (2000) studied the effects of flooding and organic matter on changes in Eh, pH, and solubility of Cd, Ni, and Zn. The redox potential (Eh) decreased after submergence. In waterlogged soil the Eh will decrease once oxygen is consumed by microbial activity; this is accompanied by an increase in pH towards neutrality. Flooding seems to have transformed Cd and Zn from a labile fraction to less labile or immobile oxide fractions. The results also showed that flooding conditions increased the organically bound fraction of Cd and Zn by 11%.

Lair et al. (2008) studied the distribution of Cd among different geochemical fractions in floodplain soils. Geochemical fractionation of original and metal-spiked soils was conducted. Cd remained in weakly bound fractions in spiked soils. Cd spiked soil was determined in five fractions which are fraction A, exchangeable or weakly sorbed; fraction B, sorbed or carbonate-bound; fraction C, strongly bound to easily reducible manganese and amorphous iron; fraction D, very strongly bound or incorporated into organic matter or other oxidizable species; fraction E, incorporated within resistant minerals. The results of distribution of Cd in original soil were divided into calcareous and non- calcareous soil, which provided the following order: fraction B ≥ fraction C > fraction A >> fraction E ≥ fraction D and fraction A = fraction C >> fraction B ≥ fraction E ≥ fraction D.

CHAPTER III

METHODOLOGY

3.1 Introduction

A pot experiment and a field experiment (selected plot experiment) were conducted in this research. Rice plants were collected to determine the bioavailability of Cd. The effects of organic fertilizer addition on Cd distribution between the different soil fractions were determined by using a sequential extraction procedure. The initial total Cd and Zn concentrations in soil were determined. The soil properties like pH, ORP, and OM were determined to clarify the effects of the amendment addition on the bioavailability. The experimental design is illustrated in Figure 3.1

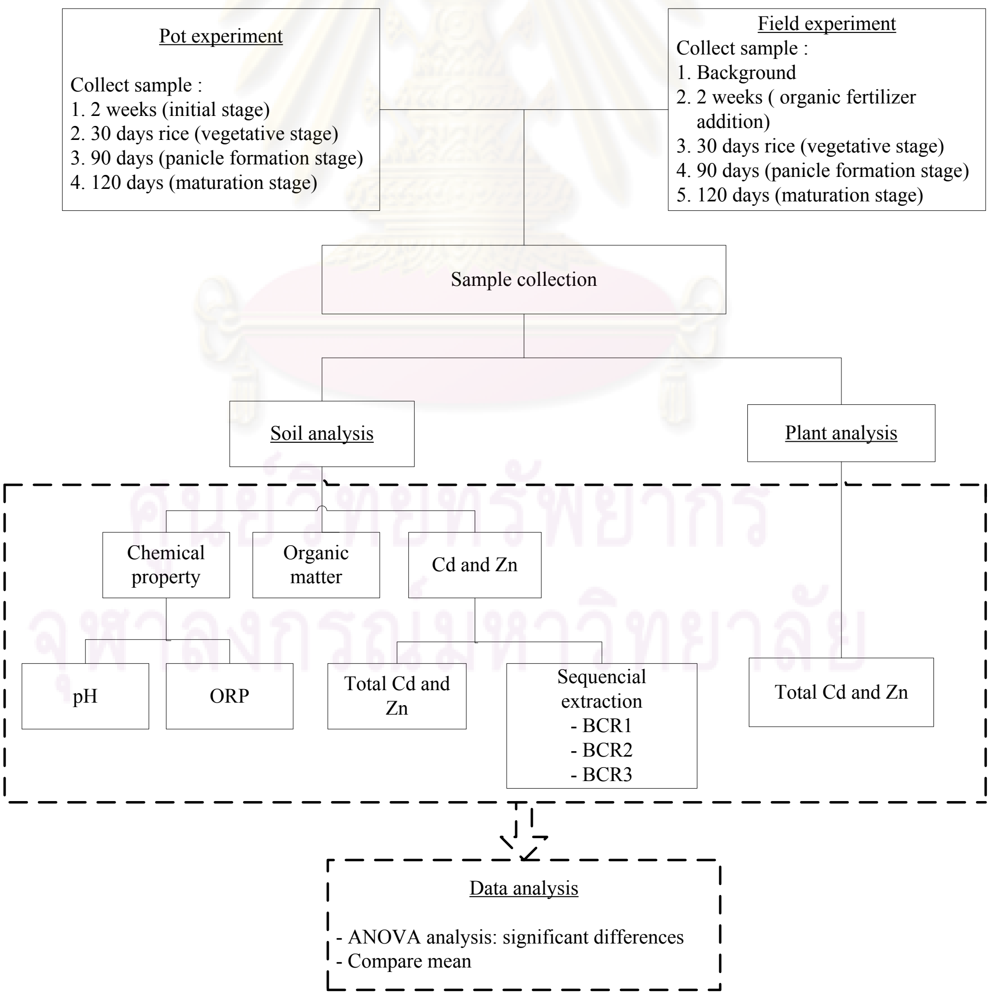

Figure 3.1 Schematic diagram of the experimental design

3.2 Study sites, preparation, and sample collection

3.2.1 Pot experiment

1. Study sites

The pot experiment was performed at the Kasetsart University, Kamphaengsaen Campus, Nakornpatom. The experimental plot was suitable for rice cultivation as it provided enough space, natural sunlight, and it was protected from rodents and insects.

2. Organic fertilizer preparation

Two types of organic fertilizers were used in this study were commercial organic fertilizer and a self-prepared organic fertilizer. The self-prepared organic fertilizer was produced by a composting process using the mass ratio of 1000: 200: 100: 0.1 of plant residuals, animal manures, urea, and a mixed culture inoculum (PD1). The incubation time was at least one month. The commercial organic fertilizer was made from composted organic waste, grinding tree, coconut filter, fruit peel, and compost at a volume ratio of 2: 1: 1: 1: 1, respectively.

3. Soil preparation

The soil used for the pot experiment was collected from the Mae Sot District, Tak Province. The initial Cd concentration in this soil was about 70 mg/kg. Soil from Mae Sot was ground, dried, and mixed to homogenize it; then, 5 kg of grinded soil was used for each experimental pot.

Organic fertilizers, 1 Mol/L KOH solution, and a combination of the organic fertilizer and the KOH solution were added into the pots containing the dried and grinded soil. Then, the soil was aged for approximately 2 weeks to reach equilibrium. The amendment ratios added are shown in Figure 3.2. Five replicates of each treatment were performed and three rice growth stages were studied (after 30, 90, and 120 days). After sowing the rice seedlings, the soil was submerged at a height of 2-5 cm above the soil level.

4. Plant preparation

Rice seeds were germinated in deionized water for 3 days. After germination, three seedlings were transplanted into the pots and after 2 weeks of growth the strongest rice plantlet was selected to obtain one plant per pot.

5. Sample collection

Soil and plant samples were collected at various rice growth stages, namely 30 days (vegetative stage), 90 days (panicle formation stage), and 120 days (maturity stage). In addition to the sample collection for the three rice growth stages, soil was collected after KOH and organic fertilizer addition to obtain values for the background conditions.

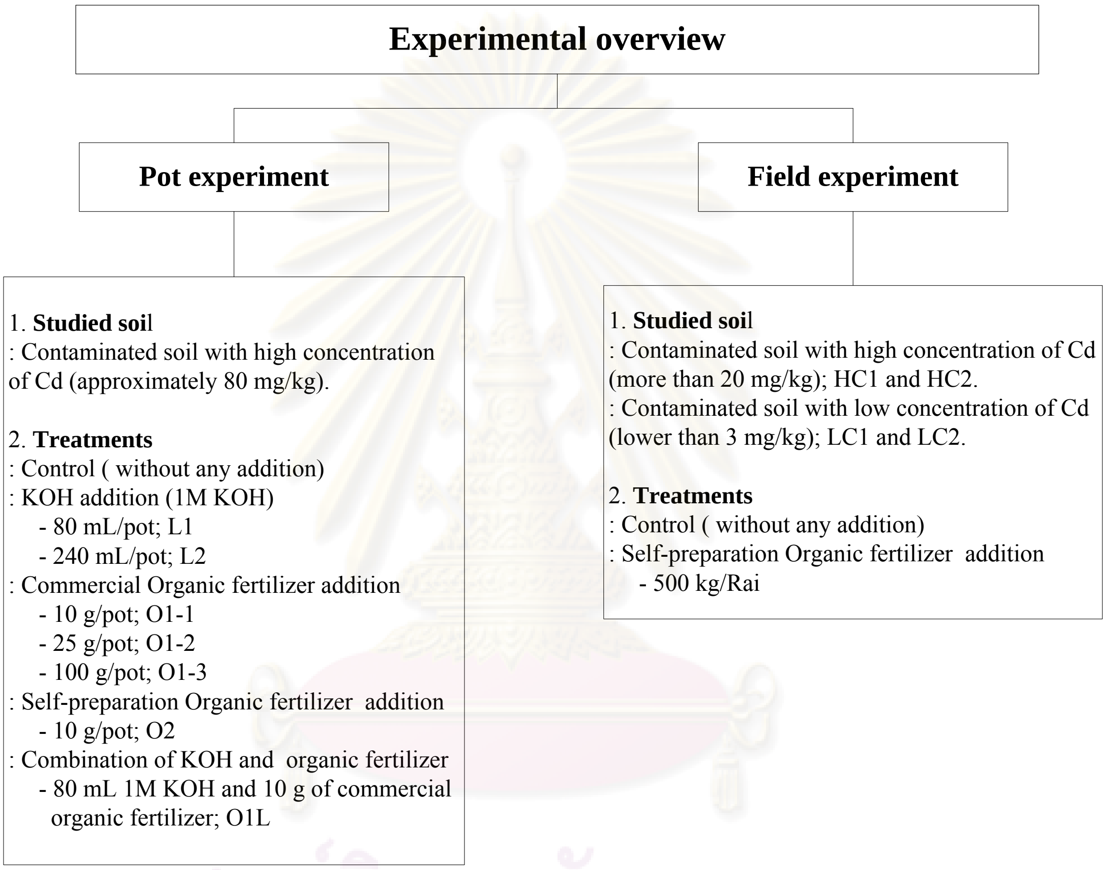

Figure 3.2 Schematic diagram of the amendment addition ratios for different treatments.

3.2.2 Field experiment

1. Site selection

Four experimental plots were selected in the Mae Sot District, Tak Province, for conducting the field experiment (compare Figure 3.3.) The four selected plots are denoted as LC1, LC2, HC1, and HC2 throughout this study. The Cd contamination of the four selected plots was in the range of 0.3-70.0 mg/kg.

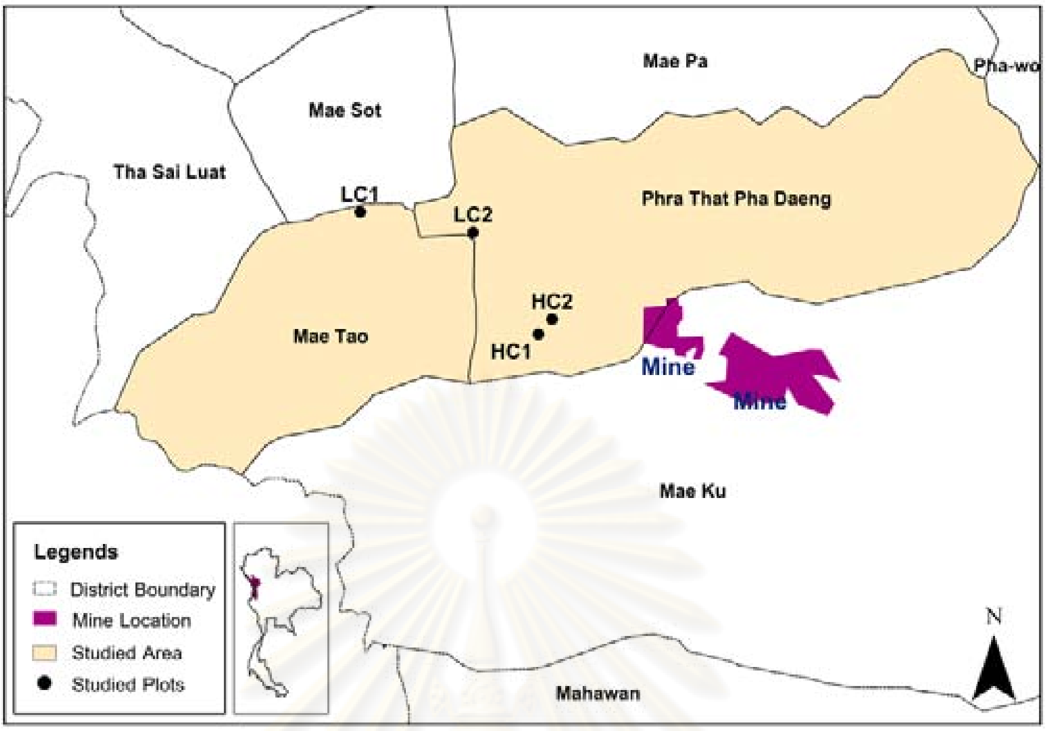

Figure 3.3 The location of the studied plots in the Mae Sot District, Tak Province.

2. Organic fertilizer preparation

The organic fertilizer used for the field study was self-prepared by applying a composting process with mass ratios of 1000: 200: 100: 0.1 of plant residuals, animal manure, urea, and a mixed culture inoculum (PD1).

3. Soil and plant preparation

The soil of the experimental field plot was prepared by applying a tillage system in order to get rid of weed. The organic fertilizer was added into the plots at a concentration of 500 kg/rai. The soil was ploughed for homogenization and to blend the added organic fertilizer; then, the soil was submerged for about 2 weeks for soil aging

4. Plant preparation

Sprouted rice seed sowing was done at another plot and 25-day-old seedlings were transplanted into the experimental plots.

5. Sample collection

Soil and plant samples were collected during various rice growth stages, namely 30 days (vegetative stage), 90 days (panicle formation stage) and 120 days (maturity stage). Before and after organic fertilizer addition soil samples were collected to gain information about the initial Cd concentration and changes of the Cd distribution between the soil fractions.

3.3 Soil analysis

3.3.1 Soil property determination

3.3.1.1 Soil characterization

Soil characterization was measured at the Soil Plant and Agricultural Material Testing and Research Unit at the Kasetsart University, Kamphaengsaen Campus. The cation exchange capacity was determined using NH4OAc at pH equal to 7.0, and the soil texture was determined using the pipette method.

3.3.1.2 Soil samples

1. The pH was determined by using a pH meter.
2. The ORP was determined by using an oxidation reduction potential meter.
3. The OM was determined by digesting the dried soil according to the Walkley-Black method by using the following procedure:

An amount of 0.5 g soil sample is placed in a 500 mL conical flask and 10 mL of 1 N $K_2Cr_20_7$ is added through a pipette. The soil and dichromate is mixed by gently swirling the flask, followed by addition of 20 mL of concentrated H_2SO_4. The flask is again swirled gently to allow an ample contact between soil and reagent. The content of the flask is allowed to stand for 30 min, followed by dilution with 100 mL of water and 10 drops of diphenylamine indicator; the solution is violet blue. The content is titrated with 0.5 Mol/L ferrous sulfate solution; when reaching the end point the solution becomes green. Then, the organic carbon and organic matter in soil can be calculated by using the following equations.

(1) % Organic C

$$\%Organic\ C = \frac{(B-S)\ x\ M\ of\ Fe^{2+}\ x 0.336}{g\ of\ soil}$$

Where;

B = Volume of Fe^{2+} solution used to titrate the blank [mL]

S = Volume of Fe^{2+} solution used to titrate the sample [mL]

(2) % Organic Matter

% Organic Matter = 1.72 x % Organic C

3.3.2 Metal determination in soil samples

The Cd and Zn concentrations in the soil samples are analyzed as fraction and total concentration by using a sequential extraction method and microwave assisted acid digestion, respectively. Distilled deionized water (18.2 MΩ) from a MilliQ water purification unit was used for preparing all solutions including adjustment throughout this study.

3.3.2.1 BCR sequential extraction

The sequential extraction procedure that was applied in this study is composed of three steps based upon the Standards, Measurements and Testing Programme of the European Union (SM&T). The first three fractions, BCR I, II, and III of Cd and Zn were determined in this study. Each extraction step was performed as follows.

BCR1: Exchangeable /Acid soluble fraction

Acetic acid (0.11 Mol/L) is added at a soil:solution ratio of 1:40 and shaken overnight for 16 h at room temperature (25 ± 5 °C). The extract is separated from the solid residue by centrifugation for 20 min at 4800 rpm, and the supernatant liquid is decanted into a polyethylene container and stored in a refrigerator at 4 °C prior to analysis. The residues are washed with 20 mL deionized water, shaken for 5 min on an end-over-end shaker and centrifuged for 20 min at 4800 rpm. The supernatant is decanted and stored at 4 °C.

BCR 2: Reducible fraction

To the residues from BCR1 (F1), 20 mL of freshly prepared hydroxylamine hydrochloride (0.1Mol/L) is added at a soil: solution ratio of 1:40 and then shaken overnight for 16 h at room temperature (25 ± 5 °C). No delay should occur between the addition of the extractant solution and the beginning of the shaking. The extract is separated from the solid phase by centrifugation and decantation as described for BCR1. The residues are then washed with 10 mL deionized water, shaken for 15 min on an end-over-end shaker and centrifuged for 20 min at 4800 rpm. The supernatant is decanted and stored at 4 °C.

BCR 3: Oxidizable fraction

To the residues from BCR 2 (F2), 8.8 Mol/L hydrogen peroxide is added at a soil:solution ratio of 1:10 and then shaken for 1 h at room temperature (25 ± 5 °C) on an end-over-end shaker. The solution is heated up to 85 °C for 1 h. The extraction is repeated by using the same procedure. Then, the samples are shaken for 16 h at 350 rpm at room temperature. The extract is separated from the solid phase by centrifugation and decantation as described for BCR1. The supernatant is decanted and stored at 4 °C (Tokalioglu et al., 2003).

3.3.2.2 Total concentration

The Cd and Zn concentrations were determined by using the microwave assisted digestion method. An amount of 0.6 g dried soil was given into a PTFE vessel and 14.5 mL of aqua regia solution was added (enhanced from microwave digestion application note manual). A aqua regia solution was prepared by mixing hydrochloric acid and nitric acid at a ratio of 3:1. This procedure was performed at a high pressure and temperature. The recommended temperature was obtained in two steps: the raising temperature, the temperature increases from room temperature until it reaches 200 °C within 10 min; and the holding temperature, the temperature holds at 200 °C throughout digestion for 20 min. After that the samples were cooled down and filtered by using a Whatman No. 41 filter paper. The volume was adjusted to 50 mL with deionized water. Total Cd and Zn concentration were measured by GFAAS and FAAS.

3.3.2.3 Plant samples

Plant samples were digested by using the wet ashing method by weighing 0.75 g of the ground plant sample into a 250 mL beaker and digest it with a strong oxidizing agent (12 mL concentrated HNO_3 and 3 mL 30% H_2O_2, adapted from the AOAC 999.10 method). The samples were covered by a watch glass for acid vapor recirculation, gently swirled, and heated on a hot plate until the brown fume disappeared. The samples were taken off the hot plate to cool down, then; 2-3 mL 30% H_2O_2 were added and heated until the solution was clear without fume formation. The samples were filtered by using a Whatman No. 41 filter paper. The volume was adjusted by deionized water. The total Cd and Zn concentration were measured by using a GFAAS or FAAS.

3.4 Quality control

For quality control, analytical blanks and certified reference material (CRM) with known concentrations of elements were analyzed using the same procedures and reagents as for the samples. To validate the method, the accuracy of the total digestion procedure for determining metals in the extracts was compared to the results of the CRM 025-050 (RTC) Lot No: JG025, Product of Resource Technology Corporation (RTC), USA. The CRM soil is moderately contaminated soil obtained from the Western United States (Matúš et al., 2005). All samples and reference materials were performed in triplicates for total acid digestion. LOD and LOQ for the GFAAS was found to be 1.64 and 4.18 µg/L, respectively,

3.5 Analytical instruments

Total digestion was performed by a microwave-assisted method using a Microwave Digestion and Extraction System, Milestone, model ETHOS PRO to digest the soil samples. The metal content of the fractions obtained by the BCR sequential extraction procedure and total metal content in the filtered solution were analyzed by a FAAS, Analytik Jena, model ZEE nit 700 and a GFAAS, Perkin Elmer, model AAnalyst 800.

3.6 Data analysis

Analysis of variance was performed using a Statistical Package for the Social Sciences (SPSS) program. Mean separations were compared using analysis of variance (ANOVA) with significant level of $P < 0.05$ and the Duncan's New Multiple Range Test (DMRT) with contrast to test the difference of the total concentration of Cd and Zn in soils and rice grain. The Duncan's New Multiple Range Tests was used to pair wise compare the mean values.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Pot experiment

Pot experiments were designed in order to evaluate the effect of lime, organic fertilizer, and mix of lime and organic fertilizer addition into contaminated soil. The concern effects in this study are on rice growth and Cd uptake to rice.

Treatments were classified into two cases; the first one was addition of potassium hydroxide as liming material (L), the second one was and organic fertilizers and the third one was the combination of organic fertilizer and liming material (O1L). In this study two types of organic fertilizer; O1 and O2 obtained from different sources. The detail will be described below. The third treatment case, O1 was used for mixing.

Figure 4.1 House surrounding for growing rice plant at Kasetsart University, Kamphaengsan Campus

4.1.1 Soil and organic fertilizer characteristics

1) Soil characteristics

The properties of studied soil for pot experiment were shown in Table 4.1. All of these properties are considered as a factor to influence to heavy metal mobilization. Clay, high SOM and high CEC is introduced to immobilize the toxic heavy metal. Heavy metal can be precipitated in basic pH. Treatment addition is mainly classified into two cases for studying the effect of potassium hydroxide as liming material (L) and organic fertilizer (O1). The combination of organic fertilizer and liming material (O1L) and another type of organic fertilizer (O2) was studied to know more understanding on feasibility of related optional approach. The specific functional group on surface of organic matter, fulvic substances and humic substances may affect to binding with metal (Yong, 2002 and Essington, 2003). CEC is a crucial property that indicates to ability of exchanging the cation, especially, the heavy metal. The initial concentration of heavy metal in soil also influences bioavailability.

Table 4.1 Soil properties and characteristics used for pot experiment

pH 1:1H_2O	SOM[a] (%)	CEC[b] (meq/100g)	Soil texture[c]: Loam			Total Cd (mg/kg)	Total Zn (mg/kg)
			%Clay	%Silt	%Sand		
7.51	5.42	18.66	13.63	47.90	38.47	81.89	3307.27

[a] SOM: Soil organic matter (Walkley and Black method); [b] CEC: Cation exchange capacity (NH4OAc, pH 7.0); [c]Soil texture (Pipette method)

The studied soil is regarded as basic pH, high SOM and moderately high CEC following the soil chemistry analysis interpretation manual, Sector of soil, compost and application testing, Kasetsart University.

2) Organic fertilizer characteristic

The individual organic fertilizer characters of two organic fertilizers were exhibited in Table 4.2. Cd concentration found in O1 is higher than O2 about two times due to difference sources. O1 was produced by organic wastes from Nonthaburi Municipality which obtained from fresh market. In addition, those organic wastes may collect without separation the small metal scraps, thereby, increasing Zn concentration in O1. However, O2 was prepared by agricultural wastes such as leave, branch and bark including cow manure which collected in uncontaminated area, the lower Cd concentration found in O2 may indicate that Cd presence in natural raw material for compost was relatively low content. SOM of O1 that found in higher amount could be that variety of organic waste providing varied organic carbon which contained in compost or organic fertilizer.

Table 4.2 The individual characters of two organic fertilizers that used for pot experiment.

	Total Cd (mg/kg)	Total Zn (mg/kg)	SOM (%)
Organic fertilizer1 (O1)	0.302	83.953	32.584
Organic ferilizer2 (O2)	0.137	56.253	27.709

4.1.2 pH and Oxidation reduction potential (ORP) in soil

pH and ORP are known to be two important factors affecting mobilization of metals in soil (Ref). So, in this study both pH and ORP of the soil were measured at all stages of sample collections.

1) pH

pH is one of the important factor that affect to available nutrients and heavy metals, therefore, the relevance of this importance is concerned about plant survival and toxicology. pH is not also important to plant but also to microbe by effecting to microbial activities which specify the degradation of organic matter in soil. Moreover, physical and chemical soil property may change due to increasing and decreasing of pH.

Soil pH was shown in Table 4.3. Organic fertilizer was added into soil with different amounts; 10 g/pot (O1-1), 25 g/pot (O1-2) and 100 g/pot (O1-3). After **2** weeks after treatment addition two weeks for ageing the studied soil (IS), only treatment with lime L-2 and mixed lime and organic fertilizer found significantly different from control.. This reason may be due to the fact that buffering capacity plays role to control pH of soil. As a consequent, L-1 which KOH was added less than L-2, Soil pH was found insignificantly different much with organic fertilizer addition as well as control. After rice plant grew up about one month (VG), soil pH was likely to reduce both in treatment addition pots and control pot except for L-2 that pH still was significantly higher than other treatments.

Table 4.3 Soil pH of all stages of rice plant growth

	Initial stages (IS)	Vegetative stage (VG)	Panicle formation stage (PF)	Maturity stage (MT)
Control	7.51 ± 0.17 [ab]	7.28 ± 0.27 [a]	7.13 ± 0.23 [ab]	7.27 ± 0.33 [cd]
L-1	7.73 ± 0.21 [b]	7.44 ± 0.11 [a]	7.52 ± 0.11 [c]	7.27 ± 0.12 [cd]
L-2	8.33 ± 0.21 [c]	7.83 ± 0.15 [b]	7.74 ± 0.13 [d]	7.64 ± 0.11 [d]
O1-1	7.58 ± 0.37 [b]	7.30 ± 0.28 [a]	7.04 ± 0.08 [a]	6.69 ± 0.18 [a]
O1-2	7.20 ± 0.10 [a]	7.19 ± 0.45 [a]	7.09 ± 0.16 [a]	6.77 ± 0.11 [ab]
O1-3	7.55 ± 0.29 [b]	7.39 ± 0.29 [a]	7.32 ± 0.08 [b]	7.07 ± 0.55 [bc]
O1L	8.10 ± 0.27 [c]	7.39 ± 0.15 [a]	7.52 ± 0.17 [c]	7.36 ± 0.18 [cd]
O2	7.57 ± 0.23 [b]	7.15 ± 0.22 [a]	7.21 ± 0.16 [ab]	7.39 ± 0.14 [cd]

Numbers followed by the same letter in each column are not significantly different at P < 0.05 by DMRT.

Figure 4.2 Rice plant grew up in liming material addition compare with organic fertilizer addition

In the VG stage, the rice plant showed the dwarfish symptom as shown in Figure 4.2 or the rice plant grew up in liming material addition and combination of organic fertilizer. Finally they were not able to survive to the third stage of the experiment. This may be due to lack of nutrients for their growth since most of micronutrient essential for plant may precipitate with hydroxide ion. Hydroxide ion is classified as hard base that has more affinity to interact with hard acids following the principle of hard and soft acids and bases which are Na^{+}, K^{+}, Be^{2+}, Mg^{2+}, Ca^{2+}, Fe^{3+} and Al^{3+} (Sparks, 1995). Besides lacking of nutrient for growth, the plant may also be severe from Cd toxicity. This can be observed from the dwarf symptom as mentioned in the first stage of planting.

The decreasing of soil pH in VG, PF and MT may result from suitable time period of ageing, root exudates, flooding, microbial activity, respiration of rice plant and neutralization by CO_2 in air. In soil with high pH, Root can release hydrogen ion or organic acids to contribute some proportion of rhizosphere acidification. Submerged soil leads to induce anoxic condition in pot; consequently, anaerobic microbes may be enhanced to promote growth. Organic acids were produced in acidogenesis stage (Mey and Roger, 2001). Furthermore, CO_2 gas from respiration by plant root and microbe including CO_2 in air may dissolve in upper water and become weak acid, carbonic acid (H_2CO_3). As this result, soil pH may slightly decrease along the experiment.

2) Redox potential

Redox potential or Eh of each stage was shown in Table 4.4. For IS stage, most of Eh was in positive range referring to low oxidizing state. This resulted from the fact that soil started to be submerged during the first 2 weeks of seedling. Later on water was added more to the pot to allow soil to be submerged at certain level and hence Eh was slightly decreased in the VG and PF stages.

Table 4.4 Oxidation-reduction potential (mV) of all stages of rice plant growth

	Initial stages (IS)	Vegetative stage (VG)	Panicle formation stage (PF)	Maturity stage (MT)
Control	103.94 ± 72.37^{b}	-85.82 ± 43.47^{a}	-172.50 ± 0.42^{cd}	-128.54 ± 50.25^{ab}
L-1	13.86 ± 74.77^{b}	-166.90 ± 63.14^{a}	-233.68 ± 24.98^{abc}	-224.24 ± 4.92^{a}
L-2	-140.10 ± 76.01^{a}	-247.38 ± 5.03^{a}	-279.10 ± 7.99^{a}	-240.74 ± 4.27^{a}
O1-1	124.78 ± 1.82^{b}	-416.42 ± 198.85^{a}	-178.04 ± 13.97^{cd}	2.74 ± 127.96^{b}
O1-2	150.58 ± 43.71^{b}	-135.72 ± 12.29^{a}	-157.74 ± 61.41^{d}	$-91.92 \pm 66.45a^{b}$
O1-3	107.76 ± 1.30^{b}	-118.06 ± 19.54^{a}	-211.12 ± 6.52^{bcd}	-118.78 ± 227.74^{ab}
O1L	37.74 ± 157.64^{b}	-172.74 ± 43.39^{a}	-240.10 ± 10.32^{ab}	-215.82 ± 0.58^{a}
O2	65.82 ± 37.89^{b}	-172.02 ± 0.37^{a}	-202.84 ± 28.40^{bcd}	-140.06 ± 112.47^{ab}

For the MT stage which the panicle already came out, Eh turned to be increased again because water was not added and gradually evaporated. Spoto (1981) defined the redox zones by Eh values in soil, for instance, Eh < 120 mV is anoxic zone. Furthermore, Spoto defined that at pH 7; oxidized soil (Eh > 414), moderately reduced soils (120 < Eh < 414), reduced soils (-120 < Eh < 120) and highly reduced soils (Eh < -120).

4.1.3 Soil organic matter

SOM content (%)was found to be increased when organic fertilizer was added in higher amount in IS stage (see Table 4.5). The after one month of the plant growth, the soil organic matter tended to slightly drop. In the next stage of PF almost experimental pots, except O1-1 and O2 showed an increased of SOM again. From observation, eutrophication of algae was seen in pot experiment and this may be a reason of SOM increasing in the PF stage.

Table 4.5 Soil organic matter (%) of all stages of rice plant growth

	Initial stages (IS)	Vegetative stage (VG)	Panicle formation stage (PF)	Maturity stage (MT)
Control	5.42 ± 0.18 ab	5.33 ± 0.19 ab	5.60 ± 0.17 ab	5.27 ± 0.29 ns
O1-1	5.54 ± 0.20 ab	5.32 ± 0.08 ab	5.18 ± 0.07 a	5.09 ± 0.22 ns
O1-2	5.60 ± 0.13 ab	5.16 ± 0.03 a	5.43 ± 0.14 ab	5.11 ± 0.63 ns
O1-3	5.74 ± 0.19 b	5.47 ± 0.19 b	5.92 ± 0.12 b	5.44 ± 0.69 ns
O1L	5.31 ± 0.25 a	5.11 ± 0.01 a	5.78 ± 0.56 b	5.22 ± 0.06 ns
O2	5.47 ± 0.22 ab	5.55 ± 0.07 b	5.58 ± 0.19 ab	5.31 ± 0.58 ns

ns; no significance at $P < 0.05$ by DMRT.

The limitation of this study was that pot samples from each stage were sacrificed. Therefore, high variation may be occurred even in the same treatment. Soil for SOM analysis was air dried to prevent lost of low molecular organic matter, thus, SOM may be fluctuated. For the MT stage, SOM had a trend to fall down finally which this reduction of SOM in paddy field was the same as result of Leaungvutiviroj et. at. (2005 in Thai).

4.1.4 Cd and Zn in Soil

4.1.4.1 Total concentration in soil

From Figure 4.3 and 4.4, Cd and Zn concentration in the IS and the MT stages were the representation of initial and final concentration during the experiment.

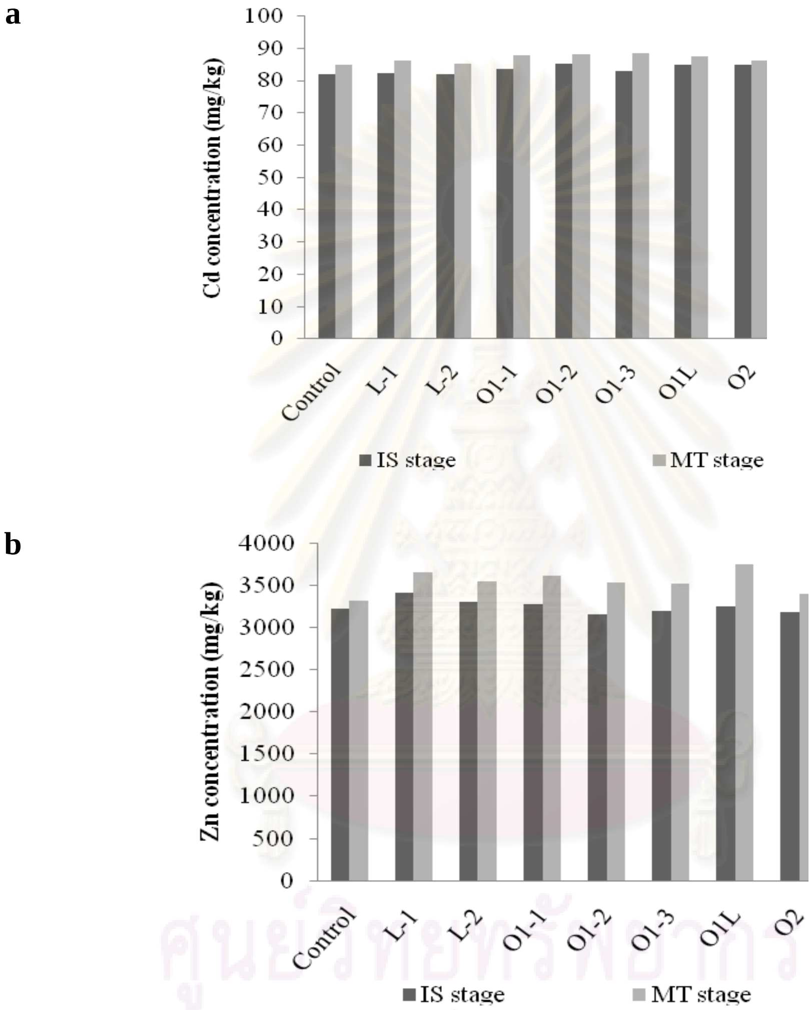

Figure 4.3 Cd (a) and Zn (b) concentration (mg/kg) of organic fertilization addition stage and maturation stage

Comparison of Cd and Zn concentration of each other in each stage also showed the fluctuation in the same range. However, this experiment showed increasing of Cd and Zn concentration in the MT stage; paired t-test analysis indicated that concentrations of both were not significantly different at $P < 0.05$. The increasing of Cd concentration is believed from the cause that SOM degradation in anoxic condition and hence reduced the soil mass in the experimental pots, thus, Cd and Zn concentration consequently increased.

4.1.4.2 Fraction in soil

Cd and Zn in soil were determined into fractions to estimate available forms which affect on uptake and accumulate in plants. In this study, only three fraction namely; the acid soluble and exchangeable (F1), reducible (F2) and oxidizable (F3) fractions were investigated in order to evaluate the change of each fraction after potassium hydroxide and organic fertilizer addition in each growth stages of rice planting. F1 and F2 are considered to be more easily uptake by plants. As a consequence, these fractions are major concerns to the environment. F3 is form of an element may absorb on the surface of organic matter. Residual fraction state is likely stable and will not be released into the environment (Song Fei et al., 1996 and Yunhong et al., 1995). Due to this reason, the residual fraction is not included in this study and F1, F2 and F3 were emphasized on availability of Cd and Zn.

1) Cd fraction in soil

As mentioned earlier that the residual fraction is relatively stable, therefore only first three fractions; F1, F2, and F3 will be evaluated as percentage of Cd proportion in order to compare the change of each fractions between different treatments. As shown in Figure 4.4, F1 was dominant fraction while F3 was the lowest proportion among these three fractions. The order of potential to be bioavailable fraction is F1 > F2 > F3. This means that Cd in F3 fraction can be considered the lowest mobilization.

Table 4.6 Cd concentration (mg/kg) of oxidizable fraction after organic fertilizer addition

	Cd concentration (mg/kg) in F3				
Initial stage	Control	O1-1	O1-2	O1-3	O2
(2 weeks after treatment)	0.793 ± 0.062^a	0.734 ± 0.115^a	0.811 ± 0.051^a	0.933 ± 0.049^b	0.902 ± 0.040^b

The organic fertilizer addition of O1 scheme in IS stage (Figure 4.4a) found that F3 of O1-3 significantly increased as shown in Table 4.6. An increase of F3 was also found for the treatment by O2 which indicated that different type of organic fertilizer influenced to ability of metal organic bound.

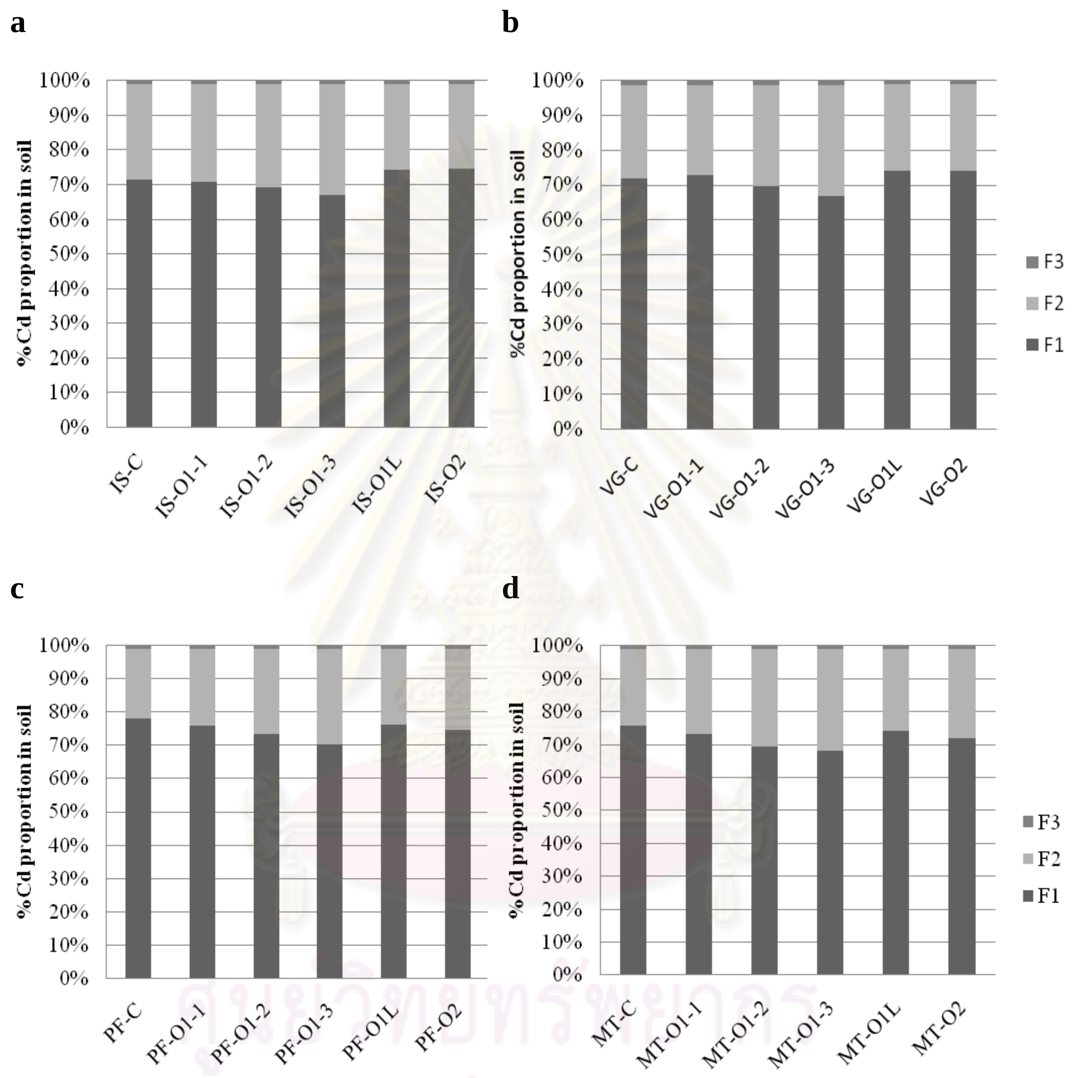

Figure 4.4 The percentage of Cd proportion in all of growth stages; **a** initial stage, **b** vegetative stage, **c** panicle formation stage and **d** maturation stage.

To consider in each stage of sampling, for the initial stage F1 of O1-2 and O2-3 significantly decreased when addition of organic fertilizer increased (Figure 4.4a). On the other hand, F2 was found reversed trend which probably can be assumed that F1 alter to F2 when organic matter of the soil increased. The same trend was found for the VG stage (Figure 4.4b). The result of O1L and O2 indicated that using different type of organic fertilizer and integrated with liming material also affected to different proportion. In the PF stages, the similar trend was found for the treatment O1, however for O1L and O2 (which organic fertilizer adding the same amount as O1-1, 10 g/pot) show similar result with O1-1 (Figure 4.4c and 4.4d).

For overall result of proportion of Cd fraction, it can be concluded that the trend is similar in all stages for the treatment O1-1, O1-2, O1-3, O2 and OL1. Even though F3 is expected to be increased, only tiny change can be observed. The Cd proportion had the similar trend in all stages.

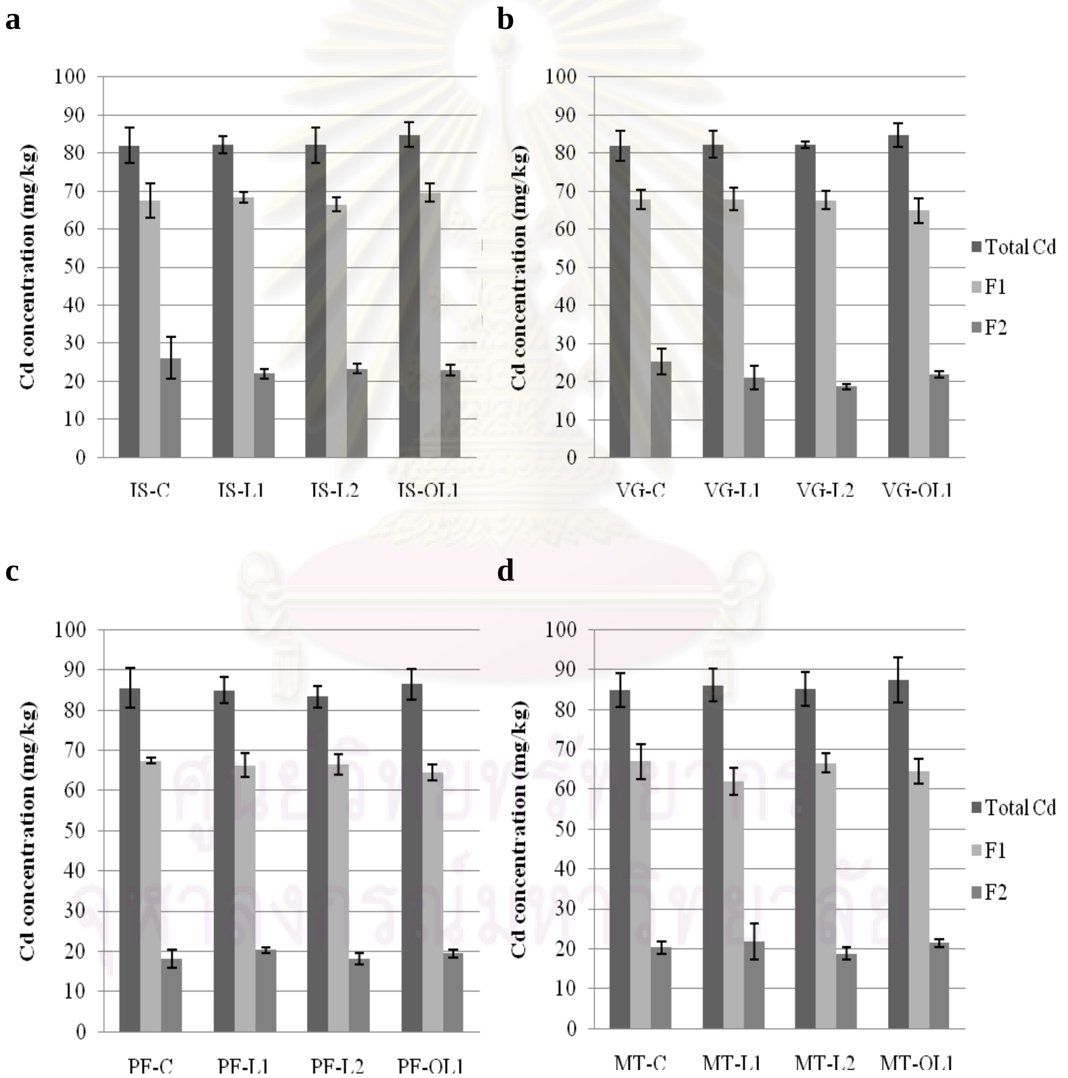

Figure 4.5 Cd concentrations of F1, F2 and total Cd with KOH addition in all of growth stages; **a** initial stage, **b** vegetative stage, **c** panicle formation stage and **d** maturation stage.

For liming treatment, as mentioned earlier soil pH of L1 and L2 were 7.73 and 8.33, respectively in the initial stage. However, once the period of planting was getting longer to VG, PF and MT stages, soil pH of both L1 and L2 were reduced to be in the range of 7.27 to 7.83 (see Table 4.3) Figure 4.5a showed that for the initial stage the higher the KOH addition, the lower the F1 fraction. Unlike the organic fertilizer treatment, F2 in these cases was found significantly reduced for both lime and mixing of lime and organic fertilizer treatments as compared to the control. In the VG and the PF stages (Figure 4.5b and 4.5c)- even though rice was died before the VG stage. F1and F2 of L1 and L2 appeared to be insignificantly difference due to the reduction of soil pH (Table 4.3). However, if compared the F1+F2, it was quite obviously that F1+F2 of L1 was higher than those of L2. This is corresponded to the study of Hong et al. (2007), Fernandes et al. (1999) and Brallier et al. (1996) on $Ca(OH)_2$ application to soil by decreased F1+F2 with higher $Ca(OH)_2$ addition.

2) Zn fraction in soil

Zn fraction is generally different than Cd fraction in which F2 was more prominent than F1 approximately 2 times (Figure 4.6). Addition of organic fertilizer seems to change fractionation among these 3 fractions by reducing F2 and increasing F1 and F3 in the initial stage (Figure 4.6a) However, for the VG, PF and MT stages, F3 was likely stable while F1 and F2 were fluctuation.

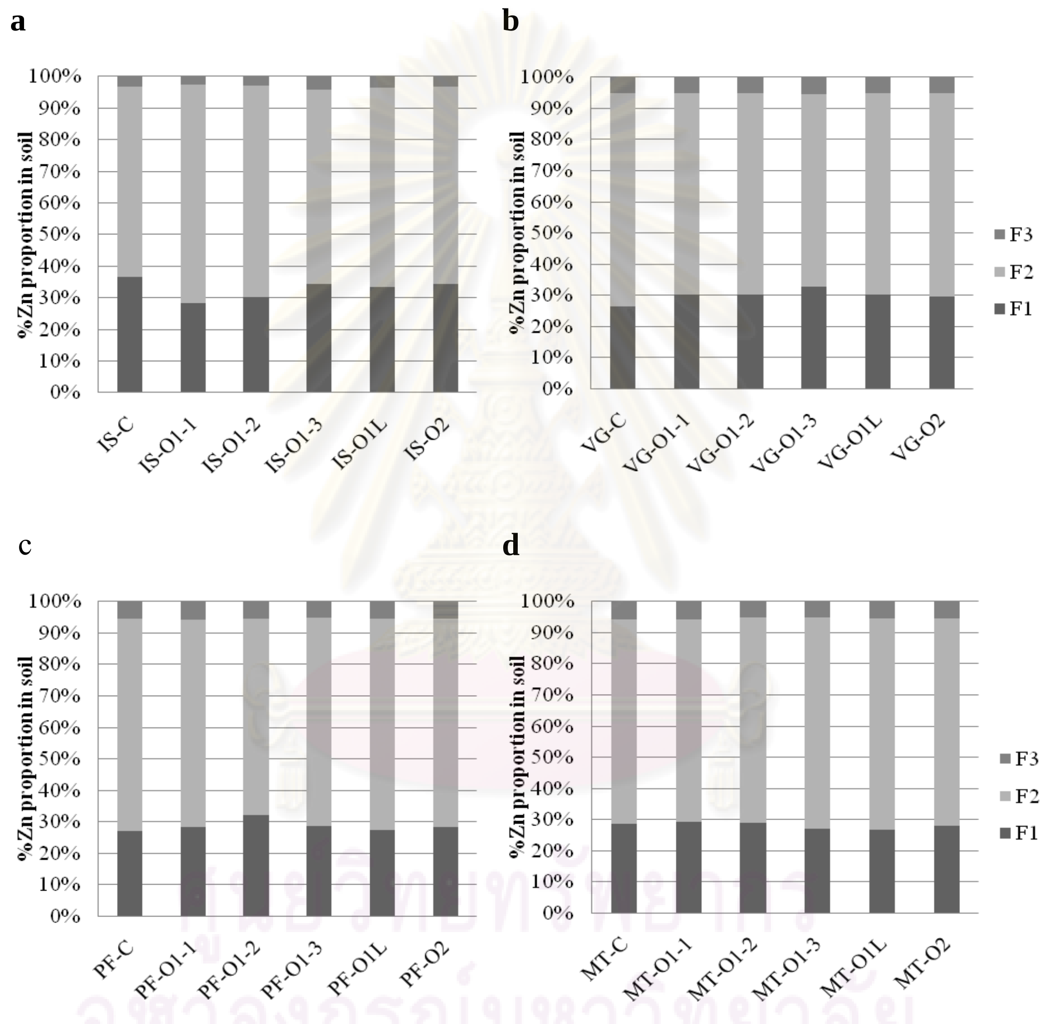

Figure 4.6 The percentage of Zn proportion in all of growth stages; **a** initial stage, **b** vegetative stage, **c** panicle formation stage and **d** maturation stage.

For KOH addition, Zn in F1fraction showed obviously decreasing in the initial stagefor all treatment related to KOH addition (Figure 4.7a). As plant roots in rhizosphere zone is able to excrete enzyme, inorganic ion and organic acid (Dakora and Phillips, 2002) that may reduce pH, thus in further stages pH is reduced and hence Zn concentration in F1 was maintained as shown in Figure 4.7b. Thereafter, once the rice plant died in PF and MT stages (Figure 4.7c and 4.7d), assuming that enzyme, inorganic ion and organic acids identified in root exudates of rice roots were no longer released, F1of L1, L2 and OL1 tended to decrease again.

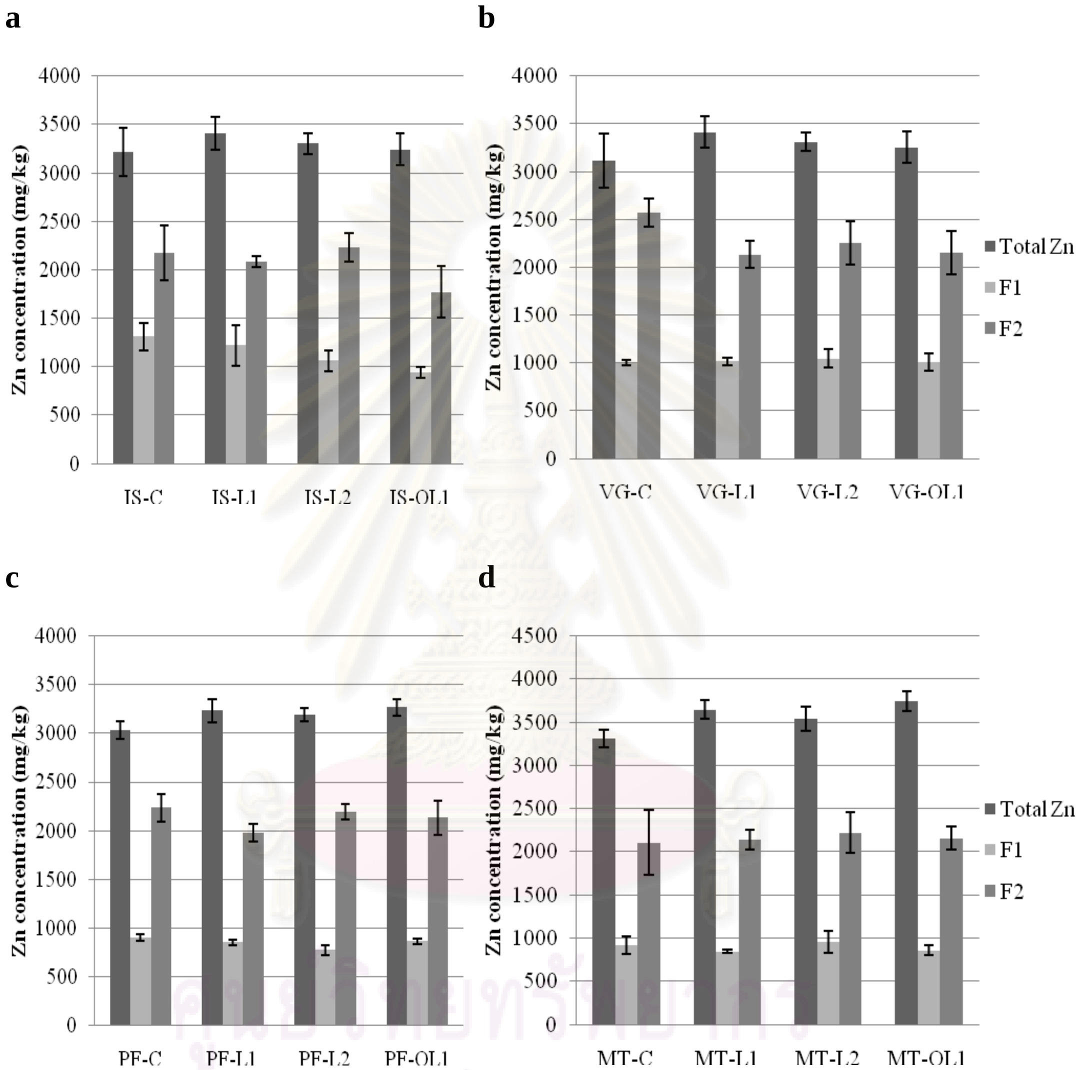

Figure 4.7 Zn concentrations of F1, F2 and total Zn with KOH addition in all of growth stages; **a** initial stage, **b** vegetative stage, **c** panicle formation stage and **d** maturation stage.

4.1.5 Rice plant of dried mass

Before analysis of Cd and Zn in plant, all parts were dried according to the method mentioned in Chapter 3. Besides being part of the method in preparation for the metal analysis, dried mass can also indirect indicate the affect of treatment on growth of rice as well. Dry mass of plant was shown in Table 4.7. Root part exhibited in the lowest mass as expected, while stem was the main part of rice yield the highest dried mass for all condition. Mass of all parts of rice plant was likely to increase by organic fertilizer (O1) addition as compared to the control, except the O1-1. For rice grain, the higher organic fertilizer addition, the higher yield was obtained. However, in this experimental pot, there was only one plant for one replicate, therefore, it is not properly to indicate the productivity or effect on plant growth from this pot experiment. For the MT stage, mass portion of root: leave: grain was approximately 1:5:2 which refer that the overall mass (more than 60%) was straw which can utilize it as raw material to produce the compost or organic fertilizer for using in further crop.

Table 4.7 Dried mass of root, stem, panicle and grain in all stages

Plant parts	Dried mass (g/plant)		
	VG	PF	MT
C-R	0.41 ± 0.47	2.28 ± 1.27	1.96 ± 0.87
O1-1-R	0.94 ± 0.72	0.56 ± 0.70	1.92 ± 0.93
O1-2-R	0.90 ± 0.64	2.34 ± 1.37	2.22 ± 1.07
O1-3-R	1.50 ± 0.64	3.97 ± 4.62	2.48 ± 1.73
O2-R	0.42 ± 0.28	1.48 ± 0.64	2.20 ± 1.59
C -T	1.79 ± 2.30	11.54 ± 4.80	12.36 ± 7.62
O1-1 -T	2.36 ± 0.95	5.48 ± 6.48	9.34 ± 6.33
O1-2 -T	3.32 ± 2.00	13.68 ± 7.44	8.16 ± 5.18
O1-3 -T	5.5 ± 1.97	11.93 ± 7.59	10.24 ± 3.75
O2-T	1.24 ± 0.89	3.53 ± 1.70	8.54 ± 6.18
C -P/ -G		2.3 ± 0.96	4.66 ± 2.69
O1-1 -P/ -G		1.17 ± 1.50	4.06 ± 2.23
O1-2 -P/ -G		3.30 ± 2.89	4.42 ± 2.98
O1-3 -P/ -G		2.15 ± 2.86	5.70 ± 3.36
O2-P/ -G		1.00 ± 1.13	5.00 ± 6.03

4.1.6 Cd and Zn in rice plant

In this part, Cd and Zn uptake to rice plant will be present only at the maturation stage (MT) in order to evaluate the effect of treatment in term of concentration as well as total accumulation in the plant. Moreover, dry mass for each stage of rice will be compared to evaluate the effect on rice growth. Since the rice plant was died out in the experimental pots of lime adding, the result discussed here is only from organic fertilizer treatment.

4.1.6.1 Cd concentration in different part of rice plant

Most of plants have their mechanism to accumulate metal in different part after uptake from soil. Root is the first part that contact directly to soil, so in most plant heavy metal (toxic ones) are found more concentrated in root than other parts (Kashem and Singh, 2001). The result from this present study also found the same case that root show the highest concentration as compared to stem and grain for all treatment including the control (Figure 4.8). The order of Cd accumulation as concentration in plant parts were found; root > stem > grain. Even though average Cd concentration in grain from organic fertilizer addition (O1-1 and O1-2) found slightly lower than the control and the lowest Cd concentration was found in grain from the treatment O1-2 at 0.267 mg/kg, due to high deviation of the result, there is insignificantly different among treatment and control and all of Cd concentration in rice grain here exceed the Codex standard at 0.2 mg/kg.

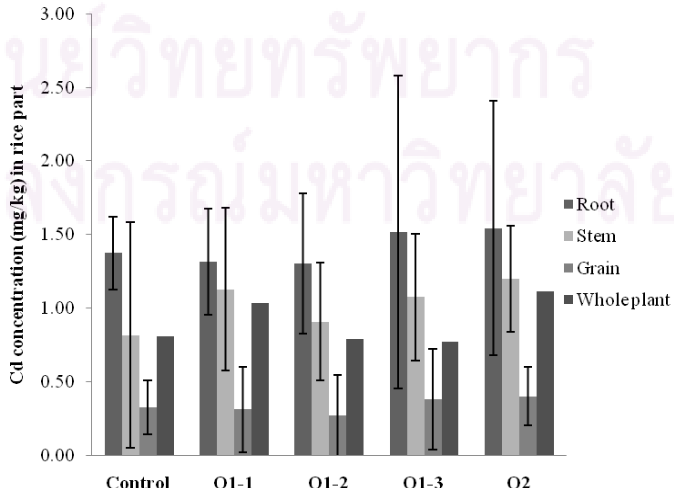

Figure 4.8 Cd concentration in rice plant parts and whole plant

However, it should be noted here that the initial concentration of Cd was very high up to 80 mg/kg as compared to previous work; most of their Cd contaminated soils have Cd less than 10 mg/kg (Hong et. al., 2006 and Boland et. al., 2003b). Consequently, even though organic fertilizer may reduced Cd in F1 fraction (as shown in Figure 4.4), Cd concentration of F1 was still very high (> 60 mg/kg) and in the limit space of experimental pot, an opportunity of available Cd to contact with root is much more than in the field. Hence, reduction of Cd in grain may not be as expected.

4.1.6.2 Zn concentration in different part of rice plant

From Figure 4.9, Zn uptake was found much higher concentration than Cd which can be ascribed that Zn is a micronutrient needed for plant growth. Similarly to Cd, Zn concentration was accumulated in the order of root > stem > grain, respectively. No such significant reduction was seen for Zn by organic fertilizer addition, even though, all four treatments found lower Zn concentration in leave and stem than those of the control. O2 The lowest Zn concentration was found in the treatment O2 at 28,439 mg/kg. In surplus Zn concentration, F1 and F2 showed the content that was sufficient for plant growth.

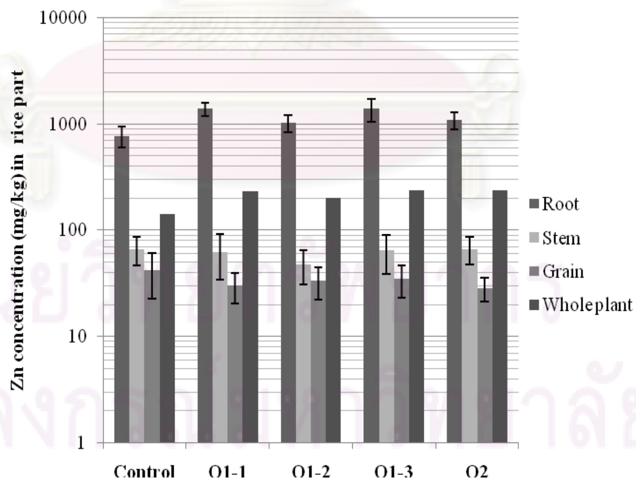

Figure 4.9 Zn concentration in rice plant parts and whole plant

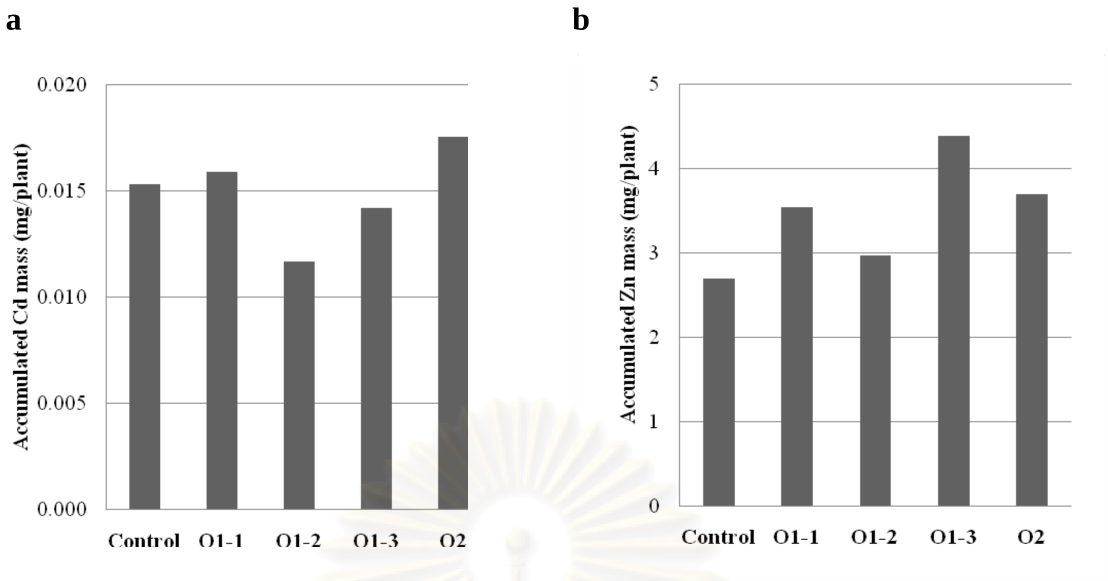

Figure 4.10 Accumulated Cd (**a**) and Zn (**b**) mass per whole plant

Cd was found lower concentration than Zn, however, the mass of plant part was equal. Therefore, Accumulated Cd and Zn mass in rice plant can be estimated the ability of Cd and Zn uptake by rice with different rate. For Figure 4.10a, Cd can be translocated to 1whole rice plant (root, stem and grain) by 0.015 mg average accumulated Cd mass (of all level of treatment in the MT stage). Figure 4.10b showed that Zn can be translocated to 1 whole rice plant (root, stem and grain) by average mass (MT stage) of 3.457 mg, respectively. Average Zn mass was found in higher amount than Cd approximately 230 times.

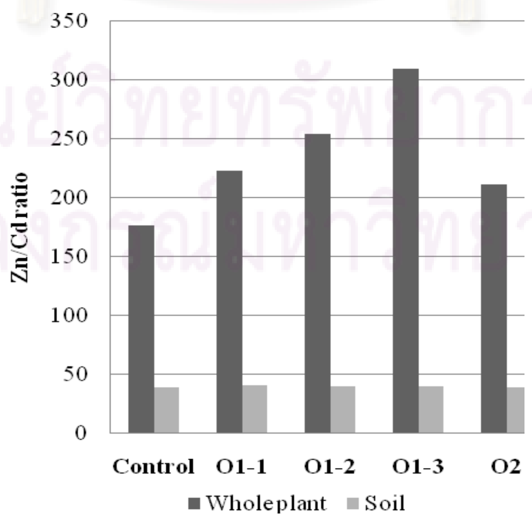

Figure 4.11 Zn/Cd ratio of accumulation in soil and whole plant for the control and the treatments

Figure 4.11 show the ratio of Zn/Cd uptake to rice from the experimental pot to those in soil. It is interesting that ratio of Zn/Cd in rice of all treatments including control are much higher than the ratio of total concentration of Zn to Cd in the soil Moreover, the higher organic fertilizer addition, the higher ratio of Zn/Cd was found in rice. This result is confirmed the affect of organic fertilizer on Cd and Zn uptake even though the mechanism lead to result is still not yet understood.

4.2 Field experiment

4.2.1 Soil and organic fertilizer characteristics

For field experiment, the self-preparing organic fertilizer was applied to four studied fields with addition rate of 500 kg/rai (referred to around 10 g/5 kg soil in experimental pot . These four different paddy fields represented the two Cd contaminated soils in low Cd concentration (LC1 and LC2) and the two high Cd concentration soils (HC1 and HC2). Each field was divided to two plots for control (C) and organic fertilizer addition (OA). Soil samples were collected for 5 periods namely; prior to organic fertilizer addition or background (BG), organic fertilizer addition (OA), vegetative growth stage (VG), panicle formation stage (PF) and maturity stage, respectively.

1) Soil characteristic

Soil properties and characteristics were showed in Table 4.8. According to the soil chemistry analysis interpretation manual, Sector of soil, compost and application testing, Kasetsart University. Soil pH of LC1 and LC2 are considered slightly acidic (6.1-6.5) and neutral pH (6.6-7.3), respectively whereas the soil from HC areas showed slightly basic with pH in the range of 7.4-7.8. SOM and soil texture indicated that soil in these studied fields were fertile and suitable for cultivation.

Table 4.8 Soil properties and characteristics used for field experiment

	LC1	**LC2**	**HC1**	**HC2**
pH 1:1H_2O	6.42	6.69	7.50	7.62
SOM (%)	4.05	5.21	4.62	5.32
CEC (meq/100g)	15.99	21.64	13.02	14.11
Soil texture	Loam	Silty clay loam	Loam	Loam
- **%Clay**	27.44	36.99	24.84	13.63
- **%Silt**	47.63	47.87	42.13	47.90
- **%Sand**	24.93	15.14	33.03	38.47
Total Cd (mg/kg)	0.32±0.15	3.97±3.95	9.35±7.76	47.03±29.67
Total Zn (mg/kg)	107.02±25.21	125.32±103.04	264.41±82.27	1936.43±1439.56

For each studied filed site, the area was divided into two plots for control and treatment and 5 sampling sites for soil and plant were collected from each plot. Total concentration of Cd and Zn shown in Table 4.8 are the range from 10 sampling sites from the control and treatment plots. The filed site contained Cd contaminated in soil lower than 10 mg/kg was defined as low contamination site (LC) while the sites contained Cd contamination 10 mg/kg was defined high contamination sites (HC), respectively.

2) Organic fertilizer characteristic

The organic fertilizer used in the field study is the same as the one used for pot experiment named as “O2”. Its characteristics are as shown in Table 4.2 in 4.1.1.

4.2.2 pH and ORP in soil

1) pH

Soil pH changes of each stage were shown in Table 4.9. All soil from low Cd concentration sites (LC1 and LC2) was slightly acidic pH while soil from high Cd concentration sites (HC1 and HC2) was neutral to slightly basic pH. After organic fertilizer was added into treatment plots, soil pH in the OA stage was increased in cases of LC1 and LC2 while reduced in the cases of HC1 and HC2. So, soil pH of all sites was likely to approach to neutral pH.

Table 4.9 Soil pH of all stages of rice plant growth for field experiment

	pH				
	BG	**OA**	**VG**	**PF**	**MT**
LC1-C	6.29 ± 0.23	6.62 ± 0.12	6.53 ± 0.12	6.20 ± 0.33	6.10 ± 0.38
LC1-O	6.55 ± 0.13	6.67 ± 0.20	6.59 ± 0.10	6.53 ± 0.18	6.29 ± 0.26
LC2-C	6.92 ± 0.68	6.81 ± 0.35	6.72 ± 0.04	6.55 ± 0.21	5.67 ± 0.43
LC2-O	6.46 ± 0.30	6.30 ± 0.13	6.69 ± 0.03	6.20 ± 0.33	5.34 ± 0.30
HC1-C	7.50 ± 0.09	7.38 ± 0.54	6.97 ± 0.05	7.01 ± 0.05	7.50 ± 0.10
HC1-O	7.50 ± 0.22	7.35 ± 0.10	6.98 ± 0.10	7.12 ± 0.09	7.49 ± 0.07
HC2-C	7.64 ± 0.08	7.22 ± 0.08	6.98 ± 0.07	7.16 ± 0.09	7.44 ± 0.13
HC2-O	7.59 ± 0.21	7.28 ± 0.17	6.92 ± 0.06	7.10 ± 0.05	6.92 ± 0.17

This indirectly indicates that organic fertilizer may perform as pH buffering. In addition, water was irrigated to flood the field after organic fertilizer addition, thus, ion related to change soil pH such as H^+ and OH^- were led to reach equilibrium in soil-soil solution phase. For the VG stage, soil pH from the HC1 and HC2 further increased to neutral and tiny change for the soil from LC1 and LC2. This may be because of submerged soil introducing anoxic condition which organic acid generated by anaerobic microorganism. In the PF stage, pH was relatively at neutral for all cases. At the MT stage, in LC1 and LC2, soil pH became slightly acid while those of HC sites were neutral to slightly basic.

2) ORP or Eh

The fate and behavior of numerous elements in the soil environment are either directly or indirectly influenced by chemical reactions involving the transfer of electrons. The oxidation-reduction (redox) status of an element is a function of the abundance of electrons in a system. In a general sense, systems that are rich in electrons are termed reduced, while those that are depleted in electrons are oxidized (Essington, 2003). The most important change upon submerging a soil is a decrease in oxygen partial pressure, which accompanies a lowering of redox potential (Eh), reduction of chemical species [$O_2 \rightarrow H_2O$, $NO_3^- \rightarrow N_2$, Mn(IV) $\rightarrow$ Mn(II), Fe(III) $\rightarrow$ Fe(II), $SO4^{2-} \rightarrow S^{2-}$, CO2$\rightarrow$ CH4]. Draining a paddy soil reverses most of the above processes: Eh rises, chemical species are oxidized, soil pH decreases, and aerobic soil biota recover (Kyuma, 2004).

Table 4.10 Oxidation-reduction potential (mV) of all stages of rice plant growth for field experiment

	ORP				
	BG	**OA**	**VG**	**PF**	**MT**
LC1-C	87.80 ± 241.14	-195.46 ± 52.45	-146.62 ± 70.73	-118.16 ± 96.23	265.72 ± 131.39
LC1-O	-60.16 ± 94.64	-44.62 ± 291.41	-198.66 ± 25.75	-162.14 ± 101.97	117.92 ± 79.60
LC2-C	-15.08 ± 45.43	-160.42 ± 48.80	-221.18 ± 25.20	-226.44 ± 23.04	135.22 ± 90.92
LC2-O	49.92 ± 117.12	-121.28 ± 49.95	-206.72 ± 14.10	-189.92 ± 79.55	242.24 ± 69.27
HC1-C	-48.44 ± 78.89	-167.14 ± 35.07	-89.96 ± 68.98	-217.94 ± 47.75	180.06 ± 43.53
HC1-O	-24.58 ± 72.27	-102.14 ± 68.85	-42.20 ± 91.12	-171.96 ± 55.66	161.86 ± 49.47
HC2-C	-54.46 ± 59.22	-155.96 ± 31.45	-21.20 ± 69.50	-103.34 ± 94.62	175.62 ± 44.26
HC2-O	-88.02 ± 53.87	-139.76 ± 72.34	-148.04 ± 28.92	-166.04 ± 79.10	166.34 ± 171.11

All stages of rice growth indicated changes of ORP as shown in Table 4.10. ORP of the BG stage had both negative and positive value may be the result from rainfall retention by differ level of tilled soil. Normally, the water was flooded into paddy fields until the panicle came out, therefore, the OA, the VG and the PF stages were subjected the reducing environment. In addition, ORP was increased in the MT stage which showed the oxidizing state.

4.2.3 Soil organic matter

SOM of each stage was shown in Table 4.11. The result shows that SOM is not changed much over the periods of the experiment. Moreover, the mature leave settle down in flooded plot and anaerobic degradation occurred resulting to an increase of SOM in the PF and the MT stages. For the BG stage, SOM was different, even though, control plots and treatment plots were located adjacent.

Table 4.11 Soil organic matter (%) of all stages of rice plant growth for field experiment

	SOM (%)				
	BG	**OA**	**VG**	**PF**	**MT**
LC1-C	3.86 ± 0.32	4.20 ± 0.97	4.35 ± 0.30	4.86 ± 0.32	5.31 ± 0.64
LC1-O	4.24 ± 0.28	4.52 ± 0.26	4.30 ± 0.36	4.56 ± 0.29	5.70 ± 0.24
LC2-C	4.75 ± 0.77	5.25 ± 0.68	5.21 ± 0.50	5.23 ± 0.57	6.41 ± 0.32
LC2-O	5.66 ± 0.22	5.00 ± 0.51	5.16 ± 0.22	5.38 ± 0.43	5.64 ± 0.46
HC1-C	5.08 ± 0.38	4.67 ± 0.20	4.74 ± 0.39	4.94 ± 0.70	5.41 ± 0.79
HC1-O	4.16 ± 0.44	3.98 ± 0.61	3.71 ± 0.46	3.91 ± 0.31	5.16 ± 1.09
HC2-C	5.13 ± 0.51	6.28 ± 0.69	5.98 ± 0.33	6.17 ± 0.20	7.35 ± 0.35
HC2-O	5.50 ± 0.40	5.79 ± 0.44	5.36 ± 0.68	5.25 ± 0.81	5.60 ± 0.46

Moreover, SOM results of OA indicated that the amount of organic fertilizer added in treatment plots were not high enough to make significantly level of SOM as compared to the control plots. Increases SOM of control plots and also treatment plots of the OA stage may cause from residual harvested organic materials from the previous crop were degraded and subsequently became SOM. Above all, the heterogeneity of soil under field condition was very high by nature; therefore, the data are quite deviate and hardly predict the trend.

4.2.4 Cd and Zn in Soil

4.2.4.1 Total concentration of Cd and Zn in soil

As seen in 4.2.3, the problem of soil heterogeneity resulted to the high fluctuation of total Cd and Zn concentration in soil in the same and once comparison with the control, i.e. LC2, HC1 and HC2 (Table 4.12 and Table 4.13). This is a nature of soil in this area, most the control sites in this study were selected next the creek then a treatment one was next after in order to avoid distribution of organic fertilizer from treatment plot to the control. From this method of plot selection, it was found that the nearer the creek, the more contamination of the soil tended to be.

Table 4.12 Total Cd concentration (mg/kg) of soil of each stage for field experiment

	Total Cd (mg/Kg)				
	BG	OA	VG	PF	MT
LC1-C	0.282 ± 0.047	0.298 ± 0.046	0.199 ± 0.046	0.132 ± 0.016	0.077 ± 0.051
LC1-O	0.364 ± 0.208	0.463 ± 0.181	0.236 ± 0.053	0.197 ± 0.076	0.061 ± 0.032
LC2-C	0.462 ± 0.136	1.291 ± 0.665	0.909 ± 0.481	2.744 ± 0.361	3.041 ± 0.335
LC2-O	0.748 ± 2.081	0.348 ± 0.108	0.248 ± 0.057	1.393 ± 0.208	1.676 ± 0.420
HC1-C	15.67 ± 5.898	11.142 ± 2.943	7.684 ± 3.075	5.641± 1.493	4.700 ± 0.958
HC1-O	3.032 ± 0.863	6.975 ± 5.005	6.199 ± 1.502	2.765± 0.325	0.656 ± 0.484
HC2-C	74.90 ± 4.169	66.93 ± 9.776	68.81 ± 5.074	65.16 ± 8.644	70.92 ± 6.041
HC2-O	19.16 ± 4.701	18.22 ± 1.503	16.52 ± 2.260	51.96 ± 22.44	13.11 ± 2.679

Table 4.13 Total Zn concentration (mg/kg) of soil of each stage for field experiment

	Total Zn (mg/kg)				
	BG	OA	VG	PF	MT
LC1-C	110.4 ± 22.27	117.3 ± 12.58	108.7 ± 6.008	132.8 ± 13.572	100.4 ± 7.126
LC1-O	103.6 ± 30.08	121.1 ± 34.39	122.5 ± 26.58	132.7 ± 31.625	87.52 ± 10.65
LC2-C	178.7 ± 129.4	198.2 ± 130.2	201.4 ± 199.7	128.1 ± 32.022	246.3 ± 131.7
LC2-O	71.94 ± 5.344	70.76 ± 4.684	59.42 ± 1.764	81.77 ± 4.518	89.89 ± 5.392
HC1-C	324.5 ± 72.92	353.7 ± 62.54	345.5 ± 46.84	407.7 ± 91.40	458.7 ± 60.38
HC1-O	204.4 ± 29.93	230.9 ± 72.89	219.3 ± 25.41	235.3 ± 18.13	248.6 ± 31.13
HC2-C	3292 ± 250.9	3253 ± 613.9	3030 ± 217.7	3036 ± 327.4	2901± 316.5
HC2-O	580.1 ± 32.63	595.6 ± 15.01	592.8 ± 18.81	1135 ± 228.5	500.5 ± 69.71

4.2.4.2 Fraction in soil

1) Cd fraction in soil

Three fractions of BCR sequential extraction were conducted to study the bioavailability which F1, F2 and F3 were referred in order of high mobility, low mobility and very low mobility, respectively. Many of the transition metal cations, such as Ni^{2+}, Zn^{2+}, Cd^{2+} and Pb^{2+}, are moderately mobile in an oxidized environment. However, the relative mobility of these elements in a reduced environment is very low to immobile (Essington, 2003).

To illustrate and compare properly, Cd concentration of F1, F2 and F3 were normalized to be percentage of proportion as presented in Figure 4.12. After water was flooded, F2 increased in the OA stage while F3 of the OA stage seemed to decrease. Organic fertilizer addition was not shown the trend to increase F3 except for LC1 and HC2. However, the Cd proportion of F3 in the control plot of LC1 and HC2 was found higher than in organic fertilizer addition plot (Figure 3b), the existing organic matter in control plot of LC1 was also higher as shown in Table 4.11.

This result was revealed later by the farmers that the manure was added into control plot of LC2 and the top soil from treatment plot of HC1 was picked up to fill in another plot. In addition, F3 may be mobilized by decomposition processes. The organic fraction released in the oxidizable step is not considered very mobile or available since it is thought to be associated with stable high molecular weight humic substances that release small amounts of metals in a slow manner (Filgueiras et. al., 2002).

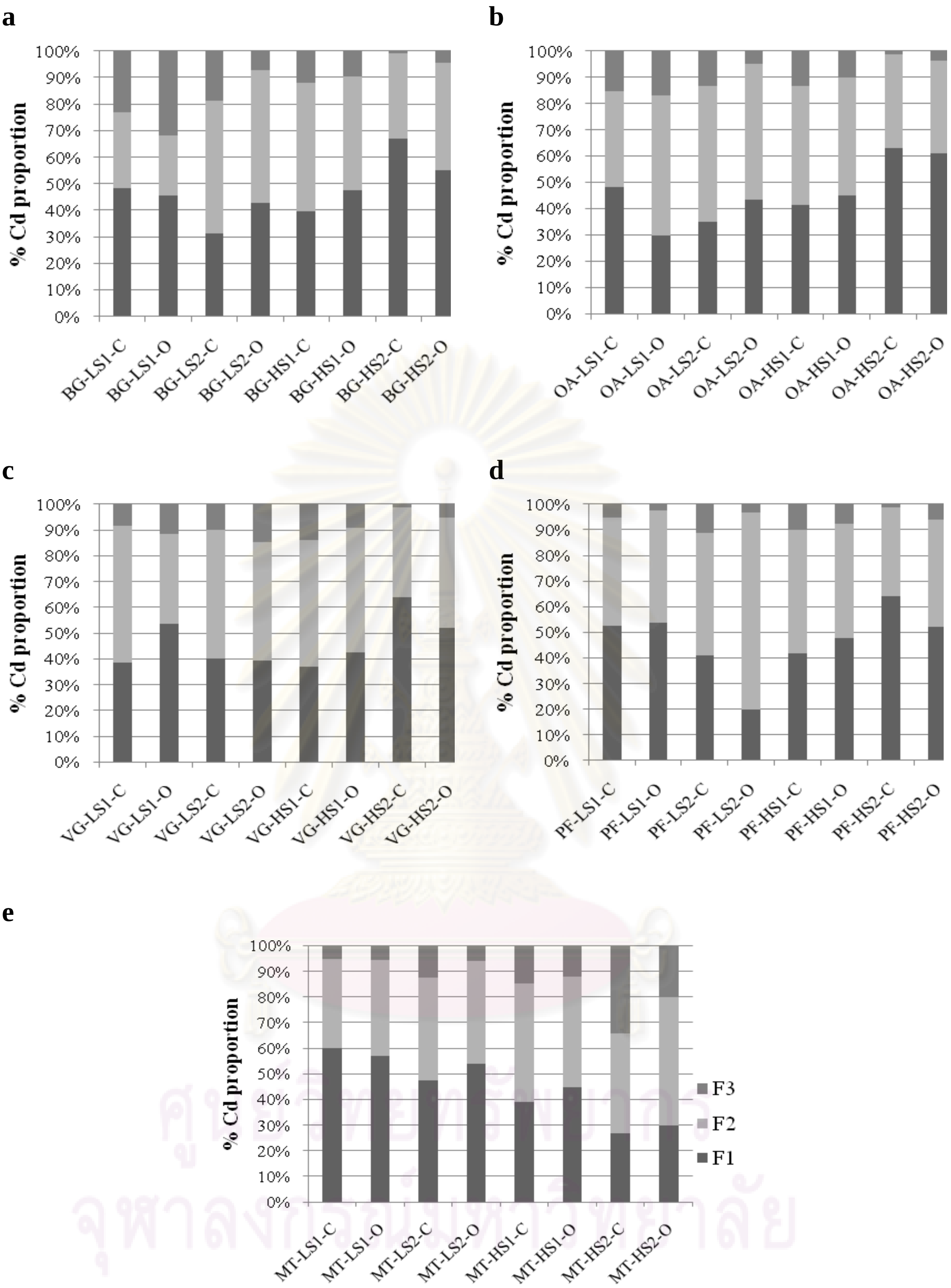

Figure 4.12 The percentage of Cd proportion in three fractions; F1, F2, and F3 in all of growth stages; **a** background stage, **b** organic fertilizer addition stage, **c** vegetative stage, **d** panicle formation stage and **e** maturation stage.

2) Zn fraction in soil

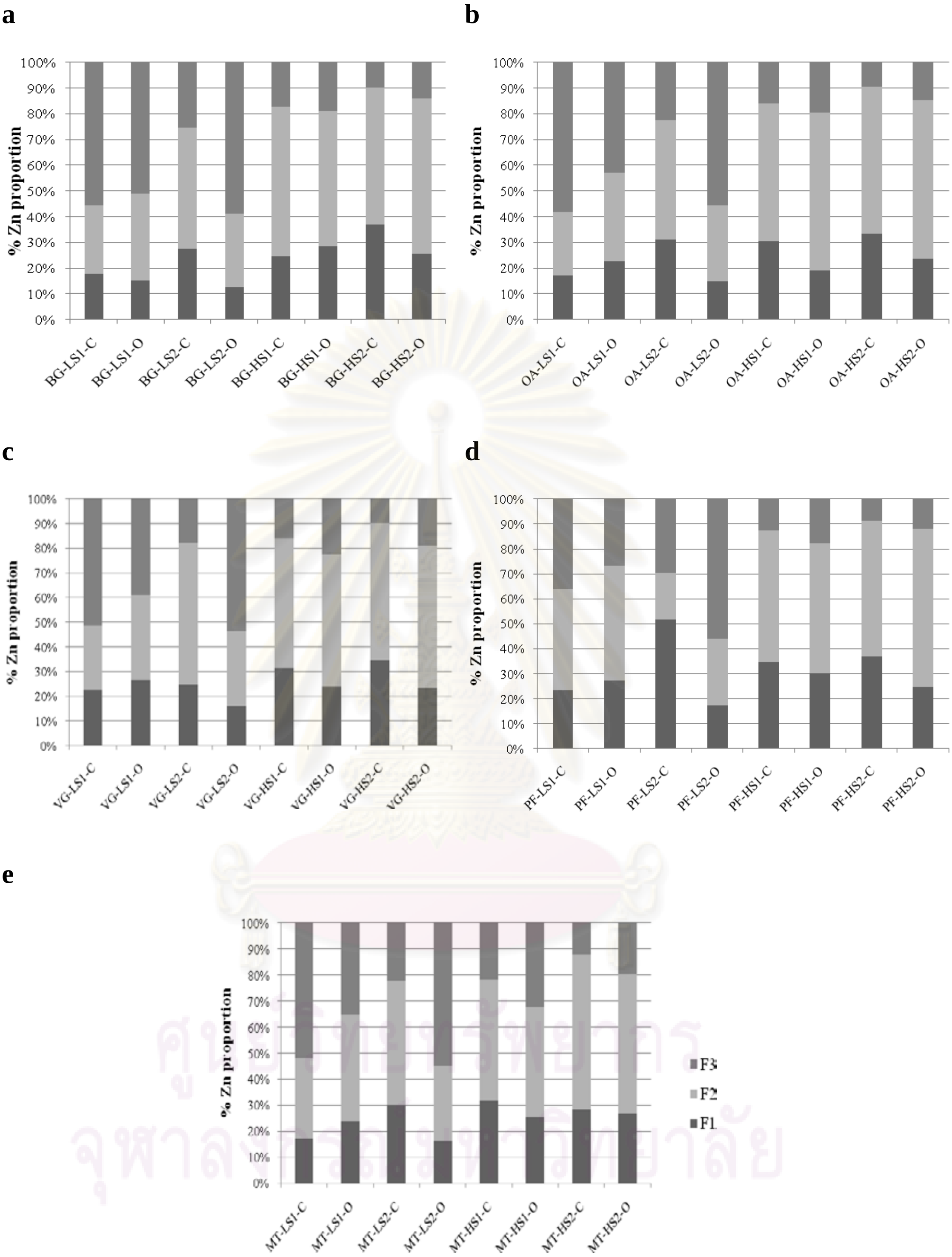

Figure 4.13 The percentage of Zn proportion in all of growth stages in three fractions; F1, F2, and F3 in all of growth stages; **a** background stage, **b** organic fertilizer addition stage, **c** vegetative stage, **d** panicle formation stage and **e** maturation stage.

Zn is found remarkable high in the studied area since this area has been classified as zinc prone or zinc deposit area Due to less mobilization of Zn than Cd, F1 and F2 proportion of Zn were found relatively low as compared to those of Cd (see Figure 4.12). Figure 4.13b showed that organic fertilizer addition did not change Zn proportion in F3 when compared with BG stage. Obviously, higher SOM of LC1 indicated the lower proportion may be due to binding with low-stable organic substances of treatment plot. The reduction of F2 proportion of LS2 in PF stage may be effected by submerged soil with low level of flooded water.

4.2.5 Cd and Zn in rice plant

Cd and Zn were investigated in three stages which are the VG, the PF and the MT stages. However, since to reduce Cd in rice grain is the expected outcome from this study, the following discussion will focus on the MT stages. Concentration of Cd will be presented

4.2.5.1 Cd in rice plant

Cd uptake by rice plants with different level of accumulation of each part is shown in Figure 4.14a. Only grain obtained from HC2 found Cd concentration exceeds the Codex standard at 0.2 mg/kg (0.706 and 0.583 mg/kg for HC2-C and HC2-O, respectively). However, if compared the treatment by organic fertilizer addition with the control, the positive effect on reducing Cd concentration in grain can be observed from LC1 and HC2 which mean that this treatment is still promising for application. For LC1, Cd accumulation showed the lowest concentration at 0.132 and 0.112 mg/kg for LC1-C and LC2-O, respectively.

Although study area was selected closely between plot of control and organic fertilizer addition, the initial concentration of Cd and Zn are still relatively different. Therefore, the comparison of the result using only concentration may not be proper for explanation. Therefore, another parameter is introduced to explain the finding of this study called “Accumulation Index”.

Accumulation Index (AI) is a parameter introduced by Kashem and Singh (2001) to estimate the relative availability of metals to plant. In this work, AI is used to normalize the Cd uptake to the rice grown in different level of Cd contamination soil. AI can be defined as ratio of unit of metal concentration in plant per 1 unit of metal concentration in soil which can be calculated by following equation;

$$\text{Accumulation Index} = \frac{\text{Mean metal concentration in plant}}{\text{Total metal concentration in soil}}$$

The determination of Cd and Zn in different parts of grown in these experiments showed the trend of accumulation index in root > stem > panicle. Cd concentration is found in each part of rice can indicate ability of uptake mechanism of the plant cells, even though the mechanism of Cd transport into plant cell may not be clearly understood yet. AI of Cd also showed the obvious trend by reversed relation that are Cd accumulated in plant part with low concentration in high Cd contamination plot (HC2) as shown in Figure 4.14b.

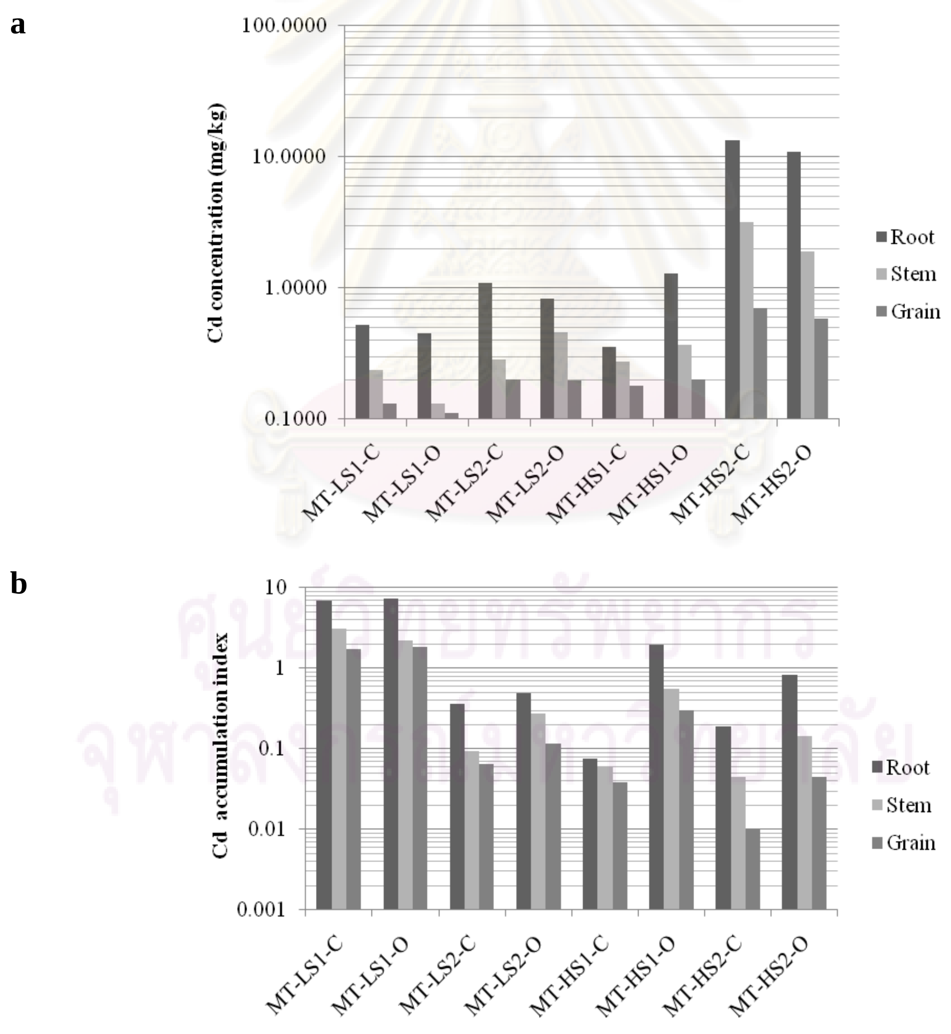

Figure 4.14 Cd concentration (a) and Cd accumulation index (b) of rice parts

This result may be explained that HC2 was regarded as the most fertile soil with high concentration of Zn, thus, the rice plants may be able to uptake nutrient with proper selectivity and uptake the pollutant with low permeability. In term of soil chemistry, Cd is a competitive element with Zn because of chemical similarity. This reason prominently supported the result of LC1 which was a represent of plot containing low SOM and Zn that showed highly ability of Cd uptake to plant parts based on the same initial Cd concentration.

4.2.5.2 Zn in rice plant

a

b

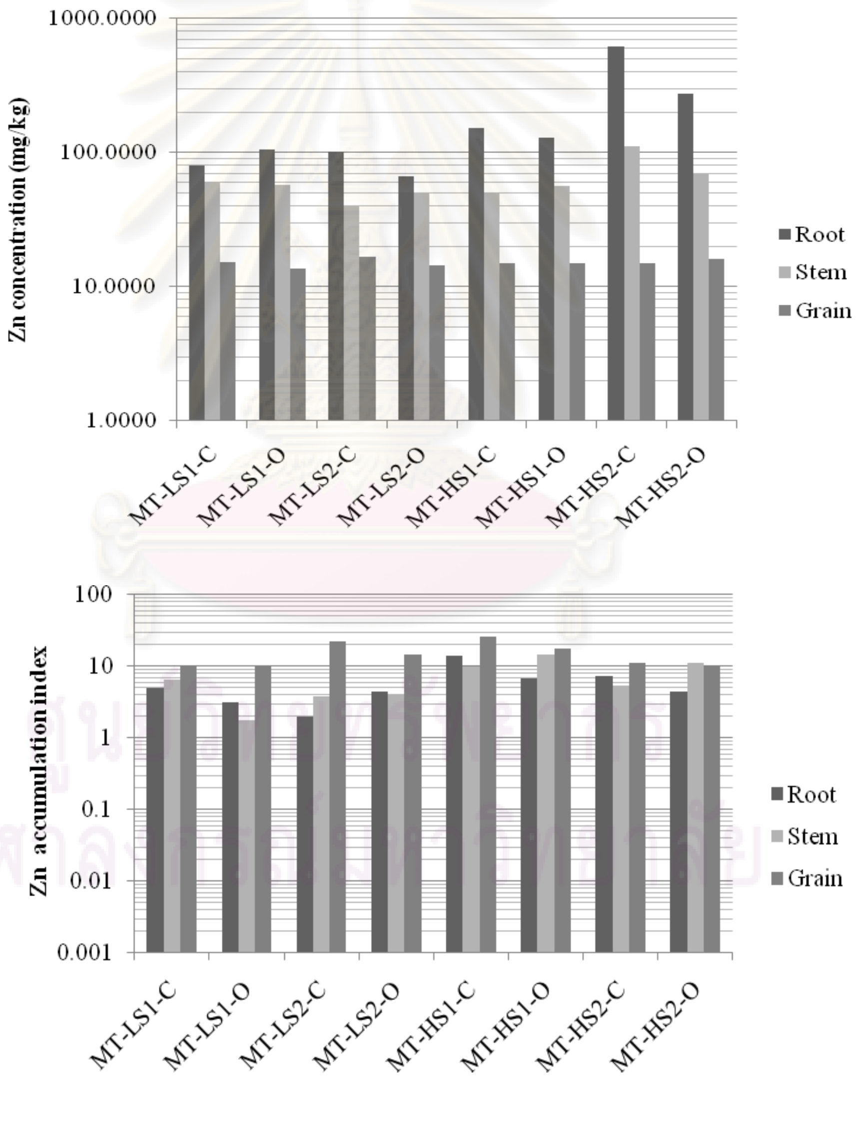

Figure 4.15 Zn concentration (a) and Zn accumulation index (b) of rice parts

Zn is the element which is one of micronutrients. Zn concentration that found in rice plant showed briefly two schemes at which LC and HC1 were firstly and HC2 was secondly. This finding showed that the initial concentration of Zn played role to increase Zn concentration in rice plant. Zn concentration showed the trend in order of root > stem > panicle which were the same as Cd. Obviously, Zn translocated to grain with a curtain concentration as shown in Figure 4.15a. However for the grain, LC1-O was found to be the lowest of Zn uptake at 13.7 mg/kg while HC2-O showed the highest of Zn concentration uptake at 16.1 mg/kg.

However, Zn AI (Figure 4.15b) showed a quite stable trend even in HC2 which can ascribe that Zn in rice plant has the same ability for uptake. Zn in grain tended to be the highest AI meant that Zn can be accumulated in grain with the highest content.

4.2.6 Rice grain productivity

To evaluate the effect of the treatments on productivity yield, the mature grain from triplicate of sub-plot with 2x3 m size were collected and air dried to estimate the yield. The rice grain productivity in Figure 4.16 was reported in unit of kg/rai with 14% moisture. If compared each pair of the treatment and control, only the case of LC1 that exhibited significantly positive effect of the treatment (524 and411 kg/rai for the treatment and the control).

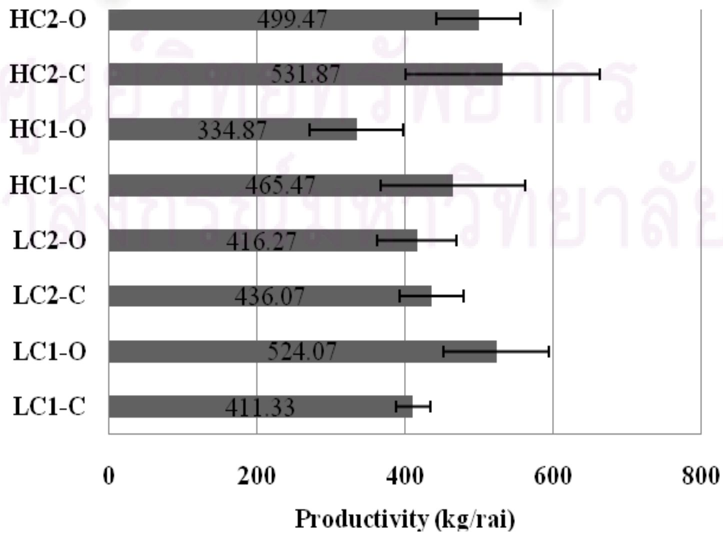

Figure 4.16 Grain productivity of each studied plot

However, for other pairs, even though the treatment shows lower productivities, from high deviation of result, it would conclude that the effect on productivity is insignificant. As a result, it can be summarized that organic fertilizer addition should not decrease productivity of the rice production. LC1 only showed a greater productivity by organic fertilizer addition. Existing SOM of each plot was regarded with this result, grain productivity related to existing SOM by getting more grain productivity when found in higher SOM.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study was conducted both pot and field experiment in order to evaluate the treatment of organic fertilizer and lime addition. The pot experiments varied the content of organic fertilizer addition at 10g, 20g and 100g per pot. Liming material used in this study was 1M KOH solution by varying two contents; 80 and 240 mL per pot. For field experiment only organic fertilizer addition was selected for onsite experiment at Mae Sot District, Tak Province, with the rate addition at 500 kg /rai following recommendation of the Land Development Department guideline for organic compost.

Organic fertilizer addition affected on increasing of SOM which may be composted of effective metal binding functional group at the surface of organic matter. Consequently, Cd was believed to be immobilized and reduced the potential phytoavailability. In this study, the three steps of BCR sequential extraction was determined to evaluate the proportion change of the three fractions; F1, F2 and F3 affected from organic compost addition. The change of each fraction is considered to influence uptake of Cd to plant since each fraction has different mobility potential.

For KOH addition, soil pH showed the trend of increasing once KOH was adding and then was gradually reduce to close to neutral pH in the vegetation stage. However, during vegetation stage, the rice plants exhibited the dwarf symptom and they finally died. This limits the evaluation of the effect lime addition on Cd uptake by rice. However, the fraction of Cd in soil had been further investigated. The result shows that after the VG stage, Cd in F1and F2 from both of L1 and L2 appeared to be insignificantly difference with those of the control. However, consideration to F1+F2, it was quite obviously that F1+F2 concentration of L1 was higher than those of L2. For Zn, F2 was the dominant fraction and F1 was maintained with high concentration before the VG stage and after that, Zn in F1 of L1, L2 and OL1 tended to decrease again in further stages.

For organic fertilizer treatment, organic fertilizer led to an increase of SOM in the soil. Cd proportion (F1, F2 and F3) showed that F1 was the dominant fraction while F3 was the lowest fraction. Some evidence indicated that F3 was increased and F1 was decreased. For Zn proportion, addition of organic fertilizer seems to change fractionation among these 3 fractions by reducing F2 and increasing F1 and F3 in the initial stage. However, for the VG, PF and MT stages, F3 was likely stable while F1 and F2 were fluctuated. Mass of all parts of rice plant was found to be increased by organic fertilizer (O1) addition as compared to the control. The order of Cd and Zn accumulation in plant parts was found in root > stem > grain. No such significant reduction was seen for Cd and Zn by organic fertilizer addition. Even though, Cd in grain from organic fertilizer addition as well as those from the control plot were found exceed to Codex standard (0.2 mg/kg), the concentration from the treatment at 10g, 20g/ pot showed less Cd concentration in grain as compared to the control.

In addition, the interesting result found in the pot experiments is that the Zn/Cd ratios in rice plant uptake from the organic fertilizer addition pots were higher than the control and correlated to amount of organic fertilizer addition. Even though the mechanism led to this effect may not be understood yet, it can be expected that organic fertilizer somehow involved in Cd and Zn reaction in the soil. The limitation of this study is that there are several factors beyond the control even in the pot experiment. As a consequent, some findings are hardly to be explained.

For the field experiment, four different paddy fields represented the two sites of low Cd contaminated soils (LC1 and LC2) and the other two sites of high Cd concentration soils (HC1 and HC2). Each field site was divided into two plots; control (C) and organic fertilizer addition (OA). The result from this study indicated that the amount of organic fertilizer added in treatment plots might not be high enough to make significantly different of SOM as compared to the control plots. Unlike pot experiment, SOM in filed experimental plot was likely to be increased in the MT stage. Organic fertilizer addition was found to be increased in F3 only for LC1 and HC2. However, since the initial concentration of SOM in the control plots of LC1 and HC2 were higher than the treatment one, the Cd proportion of F3 in the control plots were also found higher than those in the treatment plots (LC1 and HC2).

Organic fertilizer addition did not change Zn proportion in F3 when compared with the BG stage. Cd and Zn concentration in plant parts was found in root > stem >

grain. Only Cd uptake to grain obtained from HC2 found Cd concentration exceed the Codex standard at 2 mg/kg. However, if compared the treatment by organic fertilizer addition with the control, the positive effect on reducing Cd concentration in grain can be observed from LC1 and HC2 which indicate promising result from the application.

Accumulation Index (AI) was introduced as a parameter to estimate the relative availability of metals to plant based on the same initial Cd concentration. However, AI did not showed relative trend to reduce Cd and Zn in rice plants. Limitation of field experiment was heterogeneity of soil that showed different total concentration of Cd and Zn in soil including some property, especially, the differences between control and treatment plot eventhough they are adjacent.

5.2 Recommendations

The field study shows positive result on reducing Cd in rice grain, even though in the high Cd contamination site is still exceed the CODEX standard. Since organic fertilizer is applicable and has been known to maintain fertility of soil in the long term, the application of organic fertilizer should be promoted to farmers.

However, due to limitations of this study from several factors beyond the control, further studies should be carried out in order to get better understanding for further application. The recommendations for future study are as follow:

1. For the pot experiment, to reduce variation of plant and soil properties in different sampling stages. Large pot experiment to be enough for all stages of the samples collection should be introduced.
2. The extremely high Cd concentration in soil, i.e. >50 mg/kg may not be suitable for pot experiment since it is high risk for plant to survive. . For field experiment, more than one year should be follow up and the effect of organic fertilizer at various amount additions should be investigated.
3. Economic aspect should be evaluated and compare with conventional method of farmer practice.

References

Adriano, D. C. Trace elements in terrestrial environments : biogeochemistry, bioavailability, and risks of metals. 2^{nd} ed. New York: Springer, 2001.

Adriano, D.C., Wenzel, W.W., Vangronsveld, J. and Bolan, N.S. Role of assisted natural remediation in environmental cleanup. Geoderma 122 (2004): 121–142.

Alloway, B.J. Heavy Metals in Soils. London; New York: Black Academic & Professional, 1995.

Bolan, N.S., Adriano, D.C., Duraisamy, P. and Mani, A. Immobilization and phytoavailability of cadmium in variable charge soils: III. Effect of biosolid compost addition. Plant and Soil 256 (2003a): 231–241.

Bolan, N.S., Adriano, D.C., Mani, P.A. and Duraisamy, A. Immobilization and phytoavailability of cadmium in variable charge soils. II.Effect of lime addition. Plant and Soil. 251(2003b): 187–198.

Brown, S., Chaney, R. L,. and , Sprenger, M. and Compton, H. Soil remediation using biosolids using biosolids. Biocycle June (2002): 41-44

Chaney, R.L., Ryan, J.A., Li, Y.M., Welch, R.M., Reeves, P.G., Brown, S.L. and Green, C.E. Phyto-availability and bio-availability in risk assessment for cadmium in agricultural environments. Sources of Cadmium in the Environment. OECD, Paris, France, 1996.

Counce, P., Vories, E., Siebenmorgen, T., Popp, M., Thompson, V. and Watkins, B. University of Arkansas, Division of agriculture, Drainage rice by growth stage. Arkansas: The United States of America, 2005. Available from: http://cses.uark.edu/Slide1.JPG[2009, September]

Dakora, F. D. and Phillips, D. A. Root exudates as mediators of mineral acquisition in low-nutrient environments. Plant and Soil. 245(2002): 35–47.

Davidson, C.M., Duncan, A.L., Littlejohn, D., Ure, A.M. and Garden, L.M. A critical evaluation of the three-stage BCR sequential extraction procedure to assess the potential mobility and toxicity of heavy metals in industrially-contaminated land. Analytica Chimica Acta 363 (1998): 45-55.

Essington, M.E. Soil and water chemistry : an integrative approach. Florida: CRC Press, 2003.

Fei, S., Guo, Y. and Liu, X.. Effect of Compound Pollution of Cadmium, Zinc and Lead on Spinach in Brown Earth. J. AGRO-ENVIRONMENTAL PROTECTION. 15 (1996): 9-14.

Filgueiras, A.V., Lavilla, I. and Bendicho, C. Chemical sequential extraction for metal partitioning in environmental solid samples. Journal of Environmental Monitering. 4 (2002): 823–857

Gobran, G.R., Wenzel, W.W. and Lombi, E. Trace elements in the rhizophere. Florida: CRC Press, 2000.

Hanč,A., Tlustoš,P., Száková,J., Habart,J. and Gondek, K., Direct and subsequent effect of compost and poultry manure on the bioavailability of cadmium and copper and their uptake by oat biomass. Plant, Soil and Environment. 54 (2008): 271–278.

Harter, R.D.R. and Naidu, R. Role of metal–organic complexation in metal sorption by soils. Advances in Agronomy. 55(1995): 219–264.

Havlin, J.L, Beaton, J.D., Tisdale, S.L. and Nelson, W.L. Soil fertility and fertilizers: an introduction to nutrient management. 6th ed. Prentice-Hall., 1999.

Hong, C. O., Lee, D. K., Chung, D. Y. and Kim, P. J. Liming Effects on Cadmium Stabilization in Upland Soil Affected by Gold Mining Activity. Archives of Environmental Contamination and Toxicology. 52 (2007): 496–502.

Ipolyi, I., et al. Evaluation of performance of time-saving extraction devices in the BCR three-step sequential extraction procedure. Journal of Environmental Monitering. 4 (2002): 541-548.

Jozsef, H., Thomas, P., Marta, W., Walter, W.W. and Gerhand, J.S. Determination of trace elements bound to soils and sediment fractions. In IUPAC Technical Report Pure Applied Chemistry. 76 (2004): 415-442.

Kabata-Pendias, A.and Pendias, H. Trace Elements in Soils and Plants. 3rd ed. Florida: CRC Press, 2001.

Kashem, M.A. and Singh B.R. Metal availability in contaminated soils: I. Effects of flooding and organic matter on changes in Eh, pH and solubility of Cd, Ni and Zn. Nutrient Cycling in Agroecosystems. 61 (2001): 247–255.

Kennedy, V. H., Sa´nchez, A. L., Oughton, D. H. and Rowland,A. P. Use of single and sequential chemical extractants to assess radionuclide and heavy metal availability from soils for root uptake. Analyst. 122 (1997): 89R-100R.

Khai, N.M., Ha, P.Q., Vinh, N.C., Gustafsson, J.P. and Öborn, I. Effects of biosolids application on soil chemical properties in peri-urban agricultural systems. VNU Journal of Science, Earth Sciences. 24 (2008) 202-212.

Kyuma, K. Paddy soil science. Kyoto (Japan): Kyoto University Press, 2004

Lair, G.J., Graf, M., Zehetner, F. and Gerzabek, M.H. Distribution of cadmium among geochemical fractions in floodplain soils of progressing development. Environmental Pollution. 156 (2008) 207-214.

Leaungvutiviroj, C., Limthong, P. and Piriyaprin, P. Effect of organic fertilizers on methane emission from paddy soil as its affet on root system and rice yeild on Rangsit soil series. Journal of Institute of Research and Development for Soil Biotechnology. 3 (2005): 1-12.

Lee, S. Geochemistry and partitioning of trace metals in paddy soils affected by metal mine tailings in Korea. Geoderma. 135 (2006): 26– 37.

Lee, Tse-Ming, Lai, Hung-Yu, and Chen, Zueng-Sang. Effect of chemical amendments on the concentration of cadmium and lead in long-term contaminated soils. Chemosphere. 57 (2004) 1459–1471.

McLaren, R.G. and Cameron, K.C. Soil Science: Sustainable Production and Environmental Protection. 2nd ed. Oxford University Press, 1996.

McLaughlin, M.J. and Singh, B.R. Cadmium in soils and plants. Netherlands: Kluwer Academic, 1999.

Mer, L.J and Roger, P. Production, oxidation, emission and consumption of methane by soils: A review. European Journal of Soil Biology. 37 (2001): 25−50.

Murakami, M., Nakagawa, F., Ae, N., Ito, M. and Arao, T. Phytoextraction by rice capable of accumulating Cd at high levels: Reduction of Cd content of rice grain. Environmental Science Technology. 43 (2009): 5878–5883.

Pensiri Akkajit. Effects of other matals on Cd uptake by sugarcane Master's Thesis, Environmental Management, Graduate School, Chulalongkorn University, 2008.

Pichtel, J. and Bradway, D.J. Conventional crops and organic amendments for Pb, Cd and Zn treatment at a severely contaminated site, Bioresource Technology. 99 (2008) 1242–1251.

Pierzynski, G.M. and Schwab, A.P. Bioavailability of zinc, cadmium and lead in a metal contaminated alluvial soil. Journal of Environmental Quality.22 (1993): 247–254.

Selim, H.M. and Kingery W.L. Geochemical and Hydrological Reactivity of Heavy Metals in Soils. Florida: Lewis, 2001.

Semple, K.T., Doick, K.J., Jones, K.C., Burauel, P., Craven, A. and Harms, H. Defining bioavailability and bioaccessibility of contaminated soil and sediment is complicated. Environmental Science and Technology. 38 (2004): 228A–231A.

Simmons, R.W., Pongsakul, P., Saiyasitpanich, D. and Klinphoklap, S. Elevated levels of cadmium and zinc in paddy soils and elevated levels of cadmium in rice grain downstream of a zinc mineralized area in Thailand: Implications for public health. Environmental Geochemistry and Health. 27 (2005): 501-511.

Sparks, D.L. Environmental soil chemistry. Academic Press, Inc., 1995.

Spoto, G. The thermodynamics of Soil Solution. New York: Oxford Univercity Press, 1981.

Swaddiwudhipong, W., Limpatanachote, P., Mahasakpan, P., Krintratun, S. and Padungtod, C., Cadmium-exposed population in Mae Sot district, Tak Province. Journal of The Medical Association of Thailand. 90 (2007): 143-8.

The Food and Agriculture Organization of the United Nations. Irrigation Water Management: Irrigation Scheduling[online]. Rome: Italy, 1989. Available from: http://www.fao.org/docrep/T7202E/t7202e07.htm#4.3%20rice%20growth%20stages[2009, September]

Tokalioğlu, S., Kartal, S. and Bírol, G. Application of a three-stage sequential extraction procedure for the determination of extractable metal contents in highway soils. Turkish Journal of Chemistry. 27 (2003): 333-346.

Walker, D.J., Clemente, R. and Bernal, M.P. Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of Chenopodium album L. in a soil contaminated by pyritic mine waste. Chemosphere. 57 (2004): 215–224.

Yong, R.N. Geoenvironmental engineering: contaminated soils, pollutant fate and mitigation. Florida: CRC Press, 2000.

Yunhong, M. The research of regulation of transport and transport and transformation of he avy me tal in the s oil-crop system Journal of JiangSu E nvironmental Science and Technology, 1995 (1): 8-10.

Yeung, A .T. and H su, C.N. E lectrokinetic remediation of c admium c ontaminated clay. Journal of Environmental Engineering. 131 (2005): 298–304.

APPENDICES

Appendix A
Cd and Zn fractionation

Table A-1: Cd fraction for pot experiment

Code	Cd					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	ug/L	mg/kg
IS-C-S1	1.637	64.259	0.522	20.506	15.190	0.745
IS-C-S2	1.635	64.920	0.568	22.561	15.320	0.760
IS-C-S3	1.608	63.683	0.627	24.820	15.740	0.779
IS-C-S4	1.859	73.828	0.857	34.015	18.160	0.902
IS-C-S5	1.798	70.607	0.737	28.930	15.920	0.781
IS-L1-S1	1.760	69.401	0.545	21.502	-	-
IS-L1-S2	1.698	67.115	0.514	20.304	-	-
IS-L1-S3	1.760	70.106	0.602	23.963	-	-
IS-L1-S4	1.693	67.289	0.542	21.542	-	-
IS-L1-S5	1.713	67.388	0.575	22.608	-	-
IS-L2-S1	1.654	65.896	0.632	25.175	-	-
IS-L2-S2	1.722	68.647	0.592	23.584	-	-
IS-L2-S3	1.609	63.799	0.551	21.856	-	-
IS-L2-S4	1.697	67.422	0.579	22.984	-	-
IS-L2-S5	1.678	66.311	0.582	23.007	-	-
IS-O1-1-S1	1.622	64.609	0.687	27.357	17.910	0.892
IS-O1-1-S2	1.627	57.390	0.659	23.228	15.200	0.670
IS-O1-1-S3	1.657	57.435	0.608	21.085	15.450	0.669
IS-O1-1-S4	1.706	60.496	0.636	22.553	14.300	0.634
IS-O1-1-S5	1.707	67.940	0.737	29.313	16.770	0.834
IS-O1-2-S1	1.579	62.337	0.725	28.634	16.970	0.837
IS-O1-2-S2	1.671	66.270	0.692	27.456	17.290	0.857
IS-O1-2-S3	1.593	63.164	0.596	23.632	15.910	0.789
IS-O1-2-S4	1.559	61.877	0.790	31.344	16.950	0.841
IS-O1-2-S5	1.718	68.597	0.703	28.061	14.650	0.731
IS-O1-3-S1	1.544	61.748	0.707	28.286	19.450	0.972
IS-O1-3-S2	1.533	60.906	0.775	30.795	19.320	0.959
IS-O1-3-S3	1.487	59.008	0.683	27.099	18.040	0.895
IS-O1-3-S4	1.467	58.528	0.752	29.998	19.470	0.971
IS-O1-3-S5	1.537	61.004	0.682	27.053	17.440	0.865
IS-BL-S1	1.769	70.268	0.634	25.184	18.230	0.905
IS-BL-S2	1.844	73.291	0.541	21.490	17.120	0.851
IS-BL-S3	1.683	66.932	0.565	22.462	18.160	0.903
IS-BL-S4	1.757	69.255	0.576	22.720	19.520	0.962
IS-BL-S5	1.713	68.017	0.580	23.010	17.890	0.888
IS-O2-S1	1.769	70.675	0.542	21.670	18.400	0.919

Code	Cd					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	ug/L	mg/kg
IS-O2-S2	1.740	68.693	0.582	22.957	18.530	0.914
IS-O2-S3	1.595	62.783	0.513	20.197	17.470	0.860
IS-O2-S4	1.815	71.612	0.635	25.054	18.150	0.895
IS-O2-S5	1.696	67.462	0.570	22.689	17.900	0.890
VG-C-S1	1.629	64.413	0.488	19.288	20.190	0.998
VG-C-S2	1.747	69.380	0.645	25.600	25.370	1.259
VG-C-S3	1.772	70.053	0.703	27.796	21.200	1.048
VG-C-S4	1.770	69.534	0.670	26.309	26.480	1.300
VG-C-S5	1.672	65.892	0.685	27.011	23.310	1.148
VG-L1-S1	1.773	70.483	0.527	20.962	-	-
VG-L1-S2	1.693	67.343	0.471	18.751	-	-
VG-L1-S3	1.786	70.929	0.510	20.262	-	-
VG-L1-S4	1.597	63.803	0.464	18.534	-	-
VG-L1-S5	1.687	66.706	0.665	26.303	-	-
VG-L2-S1	1.767	69.403	0.497	19.529	-	-
VG-L2-S2	1.773	70.121	0.473	18.723	-	-
VG-L2-S3	1.695	67.476	0.465	18.507	-	-
VG-L2-S4	1.717	67.386	0.451	17.681	-	-
VG-L2-S5	1.596	63.763	0.475	18.965	-	-
VG-O1-1-S1	1.616	63.748	0.515	20.300	21.640	1.067
VG-O1-1-S2	1.506	60.204	0.532	21.251	20.980	1.048
VG-O1-1-S3	1.562	61.654	0.529	20.876	21.160	1.044
VG-O1-1-S4	1.542	61.045	0.657	26.002	20.810	1.030
VG-O1-1-S5	1.611	63.004	0.546	21.369	23.700	1.159
VG-O1-2-S1	1.630	64.760	0.659	26.174	21.780	1.082
VG-O1-2-S2	1.594	63.367	0.709	28.189	22.280	1.107
VG-O1-2-S3	1.555	61.706	0.611	24.258	20.990	1.041
VG-O1-2-S4	1.570	62.166	0.645	25.528	21.450	1.062
VG-O1-2-S5	1.609	64.257	0.719	28.706	20.350	1.016
VG-O1-3-S1	1.392	55.392	0.671	26.693	19.620	0.976
VG-O1-3-S2	1.370	54.625	0.692	27.600	19.430	0.968
VG-O1-3-S3	1.484	58.207	0.705	27.664	19.310	0.947
VG-O1-3-S4	1.351	53.431	0.619	24.461	18.480	0.914
VG-O1-3-S5	1.546	61.313	0.714	28.309	21.340	1.058
VG-BL-S1	1.618	64.219	0.533	21.171	17.850	0.886
VG-BL-S2	1.774	70.677	0.566	22.566	18.130	0.903
VG-BL-S3	1.623	64.087	0.533	21.058	18.720	0.924
VG-BL-S4	1.584	63.120	0.572	22.773	17.850	0.889
VG-BL-S5	1.568	62.570	0.546	21.788	17.660	0.881
VG-O2-S1	1.617	63.164	0.547	21.379	17.930	0.875
VG-O2-S2	1.603	63.523	0.589	23.349	19.040	0.943
VG-O2-S3	1.557	61.835	0.516	20.485	16.850	0.836
VG-O2-S4	1.732	68.486	0.581	22.954	18.510	0.915

Code	Cd					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	ug/L	mg/kg
VG-O2-S5	1.646	65.840	0.510	20.388	17.610	0.881
PF-C-S1	1.714	68.232	0.396	15.756	14.810	0.737
PF-C-S2	1.678	66.416	0.473	18.714	16.500	0.816
PF-C-S3	1.716	67.373	0.438	17.208	15.420	0.757
PF-C-S4	1.694	67.571	0.435	17.363	15.660	0.781
PF-C-S5	1.715	67.800	0.555	21.921	16.560	0.818
PF-L1-S1	1.576	62.552	0.491	19.504	-	-
PF-L1-S2	1.657	66.016	0.509	20.283	-	-
PF-L1-S3	1.766	70.485	0.496	19.812	-	-
PF-L1-S4	1.694	67.638	0.532	21.242	-	-
PF-L1-S5	1.627	64.628	0.517	20.532	-	-
PF-L2-S1	1.655	65.415	0.416	16.423	-	-
PF-L2-S2	1.781	70.535	0.513	20.325	-	-
PF-L2-S3	1.612	64.416	0.453	18.090	-	-
PF-L2-S4	1.699	67.811	0.462	18.431	-	-
PF-L2-S5	1.615	64.535	0.430	17.171	-	-
PF-O1-1-S1	1.670	66.627	0.508	20.275	16.610	0.828
PF-O1-1-S2	1.700	67.864	0.503	20.096	18.180	0.907
PF-O1-1-S3	1.671	66.760	0.497	19.856	17.510	0.874
PF-O1-1-S4	1.520	60.764	0.451	18.013	15.220	0.761
PF-O1-1-S5	1.656	65.806	0.550	21.856	18.840	0.936
PF-O1-2-S1	1.623	64.277	0.654	25.881	17.930	0.888
PF-O1-2-S2	1.586	62.713	0.477	18.849	15.960	0.789
PF-O1-2-S3	1.724	68.919	0.539	21.527	17.620	0.880
PF-O1-2-S4	1.701	67.701	0.494	19.650	16.460	0.819
PF-O1-2-S5	1.658	65.637	0.731	28.943	19.850	0.982
PF-O1-3-S1	1.439	57.069	0.600	23.779	18.760	0.930
PF-O1-3-S2	1.675	66.350	0.672	26.623	19.150	0.948
PF-O1-3-S3	1.545	61.407	0.656	26.053	18.260	0.907
PF-O1-3-S4	1.489	59.311	0.590	23.505	17.770	0.885
PF-O1-3-S5	1.488	59.413	0.590	23.558	18.700	0.933
PF-BL-S1	1.654	65.118	0.478	18.799	14.110	0.694
PF-BL-S2	1.561	62.415	0.482	19.268	14.650	0.732
PF-BL-S3	1.586	63.275	0.484	19.314	16.010	0.798
PF-BL-S4	1.720	67.650	0.478	18.781	15.870	0.780
PF-BL-S5	1.604	64.096	0.530	21.179	15.990	0.799
PF-O2-S1	1.745	69.675	0.558	22.276	16.910	0.844
PF-O2-S2	1.574	62.460	0.465	18.468	16.240	0.806
PF-O2-S3	1.654	65.247	0.509	20.087	16.790	0.828
PF-O2-S4	1.489	59.453	0.565	22.567	17.410	0.869
PF-O2-S5	1.636	64.946	0.526	20.865	16.260	0.807
MT-C-S1	1.679	67.093	0.450	17.970	23.320	1.165
MT-C-S2	1.789	70.656	0.534	21.094	18.270	0.902

Code	Cd					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	ug/L	mg/kg
MT-C-S3	1.539	61.096	0.549	21.786	19.610	0.973
MT-C-S4	1.612	64.377	0.497	19.840	21.200	1.058
MT-C-S5	1.801	71.696	0.521	20.756	18.820	0.937
MT-L1-S1	1.637	65.193	0.504	20.052	-	-
MT-L1-S2	1.530	60.367	0.584	23.034	-	-
MT-L1-S3	1.612	64.159	0.499	19.865	-	-
MT-L1-S4	1.420	56.687	0.726	28.994	-	-
MT-L1-S5	1.605	63.615	0.427	16.908	-	-
MT-L2-S1	1.619	64.374	0.484	19.260	-	-
MT-L2-S2	1.676	66.680	0.505	20.088	-	-
MT-L2-S3	1.686	66.287	0.486	19.123	-	-
MT-L2-S4	1.776	70.532	0.487	19.325	-	-
MT-L2-S5	1.627	64.950	0.404	16.136	-	-
MT-O1-1-S1	1.564	61.806	0.567	22.403	19.760	0.976
MT-O1-1-S2	1.594	63.557	0.605	24.119	22.470	1.120
MT-O1-1-S3	1.706	68.036	0.540	21.515	19.530	0.974
MT-O1-1-S4	1.647	65.657	0.638	25.430	20.110	1.002
MT-O1-1-S5	1.629	64.489	0.512	20.285	19.720	0.976
MT-O1-2-S1	1.660	66.334	0.557	22.254	17.860	0.892
MT-O1-2-S2	1.428	57.040	0.844	33.709	20.750	1.036
MT-O1-2-S3	1.542	61.581	0.619	24.708	19.920	0.994
MT-O1-2-S4	1.471	58.711	0.745	29.731	20.730	1.034
MT-O1-2-S5	1.593	63.290	0.527	20.950	17.370	0.863
MT-O1-3-S1	1.593	63.302	0.620	24.637	19.120	0.950
MT-O1-3-S2	1.455	57.238	0.832	32.734	21.590	1.062
MT-O1-3-S3	1.498	59.777	0.680	27.151	17.590	0.877
MT-O1-3-S4	1.539	61.364	0.681	27.161	20.470	1.020
MT-O1-3-S5	1.522	60.819	0.611	24.416	21.100	1.054
MT-BL-S1	1.708	67.994	0.554	22.070	17.870	0.889
MT-BL-S2	1.525	60.324	0.531	21.013	18.240	0.902
MT-BL-S3	1.608	64.307	0.513	20.508	19.750	0.987
MT-BL-S4	1.690	67.264	0.516	20.517	19.220	0.956
MT-BL-S5	1.576	62.814	0.575	22.921	21.500	1.071
MT-O2-S1	1.618	64.526	0.631	25.157	18.680	0.931
MT-O2-S2	1.581	63.026	0.524	20.893	19.360	0.965
MT-O2-S3	1.559	62.335	0.570	22.803	20.360	1.018
MT-O2-S4	1.595	63.294	0.680	26.992	21.200	1.052
MT-O2-S5	1.662	66.215	0.593	23.625	22.020	1.097

Table A-2: Zn fraction for pot experiment

Code	Zn					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
IS-C-S1	29.379	1153.248	48.069	1886.909	5.968	125.332
IS-C-S2	35.700	1417.510	52.668	2091.245	4.841	101.651
IS-C-S3	37.170	1472.079	49.119	1945.307	5.025	105.531
IS-C-S4	33.075	1313.542	64.092	2545.353	5.893	123.745
IS-C-S5	30.345	1191.636	60.564	2378.323	5.470	114.867
IS-L1-S1	38.241	1507.926	51.345	2024.645	-	-
IS-L1-S2	34.272	1354.625	52.710	2083.399	-	-
IS-L1-S3	26.712	1064.011	54.537	2172.356	-	-
IS-L1-S4	24.906	989.905	52.269	2077.464	-	-
IS-L1-S5	29.967	1178.875	51.891	2041.345	-	-
IS-L2-S1	29.673	1182.191	52.374	2086.614	-	-
IS-L2-S2	25.200	1004.584	54.915	2189.157	-	-
IS-L2-S3	29.463	1168.239	53.445	2119.151	-	-
IS-L2-S4	25.452	1011.204	60.396	2399.523	-	-
IS-L2-S5	23.898	944.398	60.102	2375.104	-	-
IS-O1-1-S1	23.877	951.085	59.073	2353.037	0.513	10.778
IS-O1-1-S2	23.772	838.519	62.034	2188.148	0.080	1.676
IS-O1-1-S3	24.633	853.830	51.135	1772.444	0.078	1.632
IS-O1-1-S4	23.667	839.255	55.965	1984.574	0.097	2.029
IS-O1-1-S5	23.835	948.657	61.236	2437.254	0.369	7.753
IS-O1-2-S1	22.617	892.894	48.573	1917.608	0.346	7.268
IS-O1-2-S2	24.192	959.429	56.028	2222.011	0.166	3.484
IS-O1-2-S3	23.016	912.609	50.757	2012.569	0.159	3.347
IS-O1-2-S4	28.098	1115.221	66.192	2627.188	0.264	5.539
IS-O1-2-S5	27.174	1085.007	56.511	2256.379	0.055	1.147
IS-O1-3-S1	29.127	1164.847	50.673	2026.515	6.260	131.452
IS-O1-3-S2	23.541	935.280	54.957	2183.433	6.245	131.153
IS-O1-3-S3	23.604	936.667	44.289	1757.500	5.798	121.760
IS-O1-3-S4	25.032	998.683	40.551	1617.834	5.445	114.351
IS-O1-3-S5	27.762	1101.885	41.328	1640.325	5.009	105.179
IS-BL-S1	23.940	950.943	40.845	1622.443	5.399	113.381
IS-BL-S2	25.662	1019.952	40.425	1606.717	4.498	94.462
IS-BL-S3	23.163	921.177	55.713	2215.669	4.836	101.562
IS-BL-S4	24.024	946.945	45.906	1809.460	4.979	104.561
IS-BL-S5	22.008	873.853	40.467	1606.790	4.838	101.606
IS-O2-S1	24.192	966.520	41.916	1674.630	3.738	78.498
IS-O2-S2	23.919	944.295	39.942	1576.865	4.250	89.258
IS-O2-S3	23.079	908.443	49.707	1956.583	4.047	84.981
IS-O2-S4	24.696	974.393	46.956	1852.673	4.666	97.990
IS-O2-S5	24.381	969.809	39.081	1554.535	4.269	89.655
VG-C-S1	26.397	1043.772	65.541	2591.578	3.709	183.323

Code	Zn					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
VG-C-S2	24.633	978.276	67.137	2666.283	3.955	196.336
VG-C-S3	25.410	1004.546	68.439	2705.634	3.806	188.081
VG-C-S4	24.612	966.883	65.016	2554.154	4.060	199.371
VG-C-S5	25.620	1009.655	58.989	2324.690	4.135	203.695
VG-L1-S1	25.851	1027.668	50.106	1991.890	-	-
VG-L1-S2	24.486	973.986	51.744	2058.234	-	-
VG-L1-S3	25.452	1010.802	59.451	2361.041	-	-
VG-L1-S4	24.528	979.944	52.479	2096.644	-	-
VG-L1-S5	27.384	1082.800	54.348	2148.992	-	-
VG-L2-S1	23.982	941.948	61.929	2432.404	-	-
VG-L2-S2	26.040	1029.860	57.078	2257.386	-	-
VG-L2-S3	30.555	1216.361	59.052	2350.796	-	-
VG-L2-S4	26.376	1035.165	60.186	2362.088	-	-
VG-L2-S5	25.473	1017.699	46.473	1856.692	-	-
VG-O1-1-S1	27.804	1096.805	58.296	2299.645	3.686	181.755
VG-O1-1-S2	24.822	992.285	57.729	2307.775	3.472	173.496
VG-O1-1-S3	27.909	1101.599	57.267	2260.391	3.581	176.682
VG-O1-1-S4	26.691	1056.651	53.781	2129.097	3.663	181.265
VG-O1-1-S5	24.087	942.002	53.256	2082.753	3.847	188.062
VG-O1-2-S1	24.381	968.653	58.947	2341.955	3.721	184.793
VG-O1-2-S2	24.444	971.735	54.516	2167.203	3.597	178.742
VG-O1-2-S3	31.458	1248.333	59.997	2380.833	3.467	171.974
VG-O1-2-S4	25.788	1021.105	52.983	2097.921	3.588	177.589
VG-O1-2-S5	25.872	1033.227	53.823	2149.481	3.279	163.688
VG-O1-3-S1	26.754	1064.624	52.626	2094.150	3.338	166.037
VG-O1-3-S2	23.541	938.636	36.456	1453.589	3.190	158.991
VG-O1-3-S3	27.552	1080.682	47.061	1845.891	3.163	155.079
VG-O1-3-S4	23.625	934.348	49.959	1975.835	3.490	172.533
VG-O1-3-S5	24.213	960.262	52.710	2090.422	3.051	151.249
VG-BL-S1	24.633	977.694	49.749	1974.558	3.478	172.554
VG-BL-S2	23.142	921.992	60.963	2428.805	3.374	168.028
VG-BL-S3	28.119	1110.326	54.957	2170.069	3.574	176.407
VG-BL-S4	27.720	1104.603	47.208	1881.172	3.368	167.763
VG-BL-S5	23.247	927.654	58.065	2317.039	3.420	170.591
VG-O2-S1	27.069	1057.383	56.238	2196.797	3.552	173.438
VG-O2-S2	18.570	735.895	60.165	2384.189	3.525	174.609
VG-O2-S3	29.715	1180.103	53.235	2114.178	3.303	163.969
VG-O2-S4	26.880	1062.871	62.244	2461.210	3.592	177.541
VG-O2-S5	23.814	952.560	44.499	1779.960	3.441	172.050
PF-C-S1	22.659	902.030	51.849	2064.053	3.892	193.670
PF-C-S2	23.814	942.569	59.115	2339.798	3.674	181.773
PF-C-S3	21.504	844.287	59.136	2321.790	3.547	174.077
PF-C-S4	22.449	895.453	52.668	2100.838	3.654	182.190
PF-C-S5	23.415	925.677	59.388	2347.816	3.605	178.148

Code	Zn					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
PF-L1-S1	22.050	875.174	52.689	2091.248	-	-
PF-L1-S2	20.538	818.247	48.468	1930.996	-	-
PF-L1-S3	21.714	866.653	50.715	2024.147	-	-
PF-L1-S4	22.050	880.415	50.190	2003.993	-	-
PF-L1-S5	21.063	836.663	46.578	1850.169	-	-
PF-L2-S1	20.809	822.486	58.275	2303.360	-	-
PF-L2-S2	18.539	734.210	56.322	2230.574	-	-
PF-L2-S3	19.331	772.448	53.424	2134.825	-	-
PF-L2-S4	17.728	707.571	52.395	2091.199	-	-
PF-L2-S5	20.784	830.517	55.398	2213.706	-	-
PF-O1-1-S1	21.231	847.038	56.952	2272.172	3.387	168.911
PF-O1-1-S2	22.365	892.814	55.566	2218.204	3.799	189.571
PF-O1-1-S3	20.815	831.610	51.303	2049.660	3.523	175.939
PF-O1-1-S4	21.987	878.953	45.528	1820.028	3.246	162.203
PF-O1-1-S5	24.234	963.004	47.355	1881.780	3.482	172.958
PF-O1-2-S1	24.864	984.713	44.247	1752.356	3.522	174.356
PF-O1-2-S2	33.516	1325.267	47.838	1891.578	3.334	164.788
PF-O1-2-S3	22.407	895.743	55.041	2200.320	3.447	172.247
PF-O1-2-S4	22.344	889.313	45.297	1802.866	3.429	170.597
PF-O1-2-S5	23.520	931.116	54.663	2164.014	3.652	180.721
PF-O1-3-S1	21.504	852.826	51.177	2029.625	2.885	143.020
PF-O1-3-S2	22.050	873.440	48.174	1908.259	3.377	167.211
PF-O1-3-S3	22.398	890.238	49.056	1949.762	3.119	154.958
PF-O1-3-S4	21.798	868.273	51.009	2031.826	3.381	168.343
PF-O1-3-S5	21.315	851.068	51.072	2039.209	3.177	158.565
PF-BL-S1	22.554	887.953	52.962	2085.118	3.223	158.612
PF-BL-S2	20.530	820.856	48.762	1949.700	3.245	162.185
PF-BL-S3	22.113	882.226	55.377	2209.336	3.725	185.767
PF-BL-S4	22.554	887.080	51.261	2016.165	3.771	185.398
PF-BL-S5	21.231	848.392	60.144	2403.357	3.463	172.977
PF-O2-S1	23.646	944.141	48.909	1952.845	3.507	175.035
PF-O2-S2	22.533	894.167	58.905	2337.500	3.519	174.554
PF-O2-S3	22.344	881.420	54.012	2130.651	3.462	170.710
PF-O2-S4	21.504	858.614	53.739	2145.698	3.419	170.643
PF-O2-S5	22.722	902.025	47.565	1888.249	3.671	182.166
MT-C-S1	23.310	931.469	39.501	1578.462	3.913	195.455
MT-C-S2	24.066	950.474	64.050	2529.621	3.860	190.561
MT-C-S3	25.410	1008.734	49.392	1960.778	3.526	174.970
MT-C-S4	18.329	731.981	51.723	2065.615	3.605	179.962
MT-C-S5	24.255	965.565	59.892	2384.236	3.611	179.688
MT-L1-S1	21.903	872.282	54.852	2184.468	-	-
MT-L1-S2	21.084	831.880	56.679	2236.299	-	-
MT-L1-S3	21.336	849.194	56.637	2254.209	-	-
MT-L1-S4	21.021	839.162	49.791	1987.665	-	-

Code	Zn					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
MT-L1-S5	21.105	836.504	51.597	2045.065	-	-
MT-L2-S1	21.399	850.855	58.548	2327.952	-	-
MT-L2-S2	23.352	929.063	64.848	2579.988	-	-
MT-L2-S3	25.389	998.191	51.996	2044.270	-	-
MT-L2-S4	28.959	1150.079	52.899	2100.834	-	-
MT-L2-S5	20.790	829.940	51.051	2037.964	-	-
MT-O1-1-S1	21.084	833.195	48.510	1917.012	3.338	164.888
MT-O1-1-S2	23.457	935.287	46.284	1845.455	3.607	179.775
MT-O1-1-S3	23.079	920.399	62.916	2509.113	3.407	169.840
MT-O1-1-S4	24.192	964.401	45.171	1800.718	3.588	178.792
MT-O1-1-S5	22.008	871.259	50.358	1993.587	3.463	171.368
MT-O1-2-S1	21.798	871.049	56.721	2266.573	3.329	166.284
MT-O1-2-S2	22.638	904.254	50.085	2000.599	3.110	155.283
MT-O1-2-S3	22.092	882.268	52.857	2110.903	2.949	147.214
MT-O1-2-S4	21.672	864.977	51.597	2059.349	3.198	159.549
MT-O1-2-S5	23.226	922.765	41.013	1629.440	3.159	156.883
MT-O1-3-S1	21.861	868.707	60.459	2402.503	3.331	165.458
MT-O1-3-S2	21.504	845.948	48.279	1899.253	3.116	153.226
MT-O1-3-S3	21.063	840.503	53.382	2130.168	2.793	139.316
MT-O1-3-S4	20.681	824.593	48.657	1940.072	3.355	167.215
MT-O1-3-S5	21.168	845.874	53.865	2152.448	3.419	170.779
MT-BL-S1	19.530	777.468	56.238	2238.774	3.270	162.719
MT-BL-S2	20.933	828.038	50.001	1977.888	3.365	166.386
MT-BL-S3	21.966	878.464	53.130	2124.775	3.465	173.215
MT-BL-S4	22.407	891.821	58.674	2335.284	3.474	172.836
MT-BL-S5	22.848	910.642	52.983	2111.718	3.577	178.208
MT-O2-S1	22.491	896.949	48.888	1949.671	3.485	173.729
MT-O2-S2	21.525	858.083	62.706	2499.741	3.419	170.371
MT-O2-S3	19.391	775.346	50.337	2012.675	3.791	189.474
MT-O2-S4	22.974	911.667	55.356	2196.667	3.312	164.286
MT-O2-S5	27.006	1075.936	50.106	1996.255	3.691	183.815

Table A-3: Cd fraction for field experiment

Code	Cd					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
BG-LC1-C1	0.001	0.026	0.000	0.019	0.000	0.023
BG-LC1-C2	0.001	0.055	0.001	0.029	0.000	0.014
BG-LC1-C3	0.001	0.029	0.000	0.018	0.000	0.014
BG-LC1-B1	0.001	0.058	0.000	0.016	0.001	0.032
BG-LC1-B2	0.001	0.028	0.001	0.021	0.001	0.027
BG-LC1-B3	0.001	0.033	0.001	0.022	0.000	0.024
BG-LC2-C1	0.015	0.578	0.032	1.252	0.008	0.393
BG-LC2-C2	0.021	0.812	0.033	1.305	0.008	0.394
BG-LC2-C3	0.013	0.513	0.013	0.516	0.007	0.360
BG-LC2-B1	0.007	0.281	0.008	0.314	0.001	0.033
BG-LC2-B2	0.005	0.198	0.006	0.252	0.001	0.056
BG-LC2-B3	0.006	0.226	0.007	0.263	0.001	0.035
BG-HC1-C1	0.032	1.262	0.033	1.304	0.005	0.273
BG-HC1-C2	0.034	1.330	0.037	1.450	0.009	0.434
BG-HC1-C3	0.018	0.707	0.031	1.250	0.006	0.306
BG-HC1-B1	0.022	0.869	0.022	0.869	0.005	0.230
BG-HC1-B2	0.032	1.286	0.026	1.050	0.004	0.202
BG-HC1-B3	0.016	0.634	0.015	0.590	0.003	0.131
BG-HC2-C1	1.349	52.975	0.837	32.876	0.017	0.827
BG-HC2-C2	1.708	67.805	0.640	25.411	0.016	0.783
BG-HC2-C3	1.769	69.632	0.827	32.545	0.017	0.851
BG-HC2-B1	0.212	8.452	0.132	5.281	0.012	0.609
BG-HC2-B2	0.192	7.620	0.179	7.107	0.013	0.651
BG-HC2-B3	0.179	7.069	0.116	4.583	0.011	0.547
OA-LC1-C1	0.001	0.042	0.001	0.033	0.000	0.014
OA-LC1-C2	0.001	0.057	0.001	0.044	0.000	0.024
OA-LC1-C3	0.002	0.070	0.001	0.053	0.000	0.016
OA-LC1-B1	0.001	0.033	0.002	0.070	0.000	0.007
OA-LC1-B2	0.001	0.030	0.001	0.027	0.000	0.016
OA-LC1-B3	0.001	0.030	0.002	0.066	0.001	0.029
OA-LC2-C1	0.023	0.926	0.029	1.167	0.007	0.340
OA-LC2-C2	0.018	0.729	0.029	1.137	0.008	0.392
OA-LC2-C3	0.013	0.527	0.023	0.895	0.002	0.094
OA-LC2-B1	0.007	0.259	0.008	0.322	0.001	0.029
OA-LC2-B2	0.003	0.129	0.007	0.284	0.000	0.013
OA-LC2-B3	0.007	0.291	0.005	0.208	0.001	0.036
OA-HC1-C1	0.030	1.195	0.036	1.431	0.010	0.514
OA-HC1-C2	0.032	1.261	0.034	1.368	0.007	0.352
OA-HC1-C3	0.032	1.270	0.033	1.310	0.007	0.345
OA-HC1-B1	0.032	1.250	0.035	1.393	0.006	0.293
OA-HC1-B2	0.018	0.732	0.019	0.750	0.003	0.171
OA-HC1-B3	0.023	0.927	0.019	0.771	0.004	0.178
OA-HC2-C1	1.236	49.322	0.564	22.502	0.018	0.874
OA-HC2-C2	0.858	34.045	0.586	23.251	0.015	0.769
OA-HC2-C3	0.923	45.270	0.547	26.816	0.016	0.992

Code	Cd					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
OA-HC2-B1	0.270	10.679	0.160	6.307	0.014	0.691
OA-HC2-B2	0.209	8.297	0.136	5.402	0.013	0.657
OA-HC2-B3	0.286	11.263	0.143	5.634	0.011	0.557
VG-LC1-C1	0.001	0.059	0.003	0.129	0.000	0.013
VG-LC1-C2	0.005	0.203	0.003	0.125	0.000	0.017
VG-LC1-C3	0.001	0.034	0.004	0.152	0.001	0.033
VG-LC1-B1	0.001	0.031	0.002	0.069	0.000	0.017
VG-LC1-B2	0.001	0.031	0.002	0.071	0.000	0.014
VG-LC1-B3	0.007	0.265	0.002	0.073	0.001	0.040
VG-LC2-C1	0.019	0.760	0.024	0.968	0.008	0.374
VG-LC2-C2	0.021	0.834	0.027	1.066	0.004	0.216
VG-LC2-C3	0.023	0.918	0.027	1.086	0.001	0.030
VG-LC2-B1	0.008	0.300	0.008	0.326	0.005	0.244
VG-LC2-B2	0.006	0.251	0.006	0.250	0.001	0.025
VG-LC2-B3	0.006	0.224	0.008	0.329	0.000	0.019
VG-HC1-C1	0.034	1.334	0.035	1.401	0.009	0.460
VG-HC1-C2	0.019	0.753	0.032	1.271	0.008	0.375
VG-HC1-C3	0.024	0.956	0.034	1.365	0.007	0.328
VG-HC1-B1	0.019	0.774	0.018	0.708	0.003	0.147
VG-HC1-B2	0.020	0.776	0.020	0.786	0.003	0.148
VG-HC1-B3	0.011	0.438	0.019	0.758	0.003	0.132
VG-HC2-C1	1.202	47.962	0.836	33.363	0.019	0.941
VG-HC2-C2	1.301	51.251	0.586	23.065	0.016	0.808
VG-HC2-C3	1.251	49.594	0.643	25.475	0.018	0.883
VG-HC2-B1	0.143	5.659	0.183	7.242	0.015	0.763
VG-HC2-B2	0.243	9.685	0.176	7.006	0.015	0.768
VG-HC2-B3	0.190	7.529	0.113	4.474	0.014	0.679
PF-LC1-C1	0.005	0.203	0.004	0.166	0.001	0.028
PF-LC1-C2	0.006	0.242	0.005	0.188	0.000	0.017
PF-LC1-C3	0.006	0.243	0.005	0.195	0.000	0.023
PF-LC1-B1	0.007	0.269	0.006	0.236	0.000	0.009
PF-LC1-B2	0.012	0.456	0.007	0.280	0.000	0.021
PF-LC1-B3	0.010	0.392	0.010	0.400	0.000	0.021
PF-LC2-C1	0.019	0.755	0.008	0.316	0.005	0.224
PF-LC2-C2	0.011	0.443	0.011	0.448	0.004	0.177
PF-LC2-C3	0.008	0.325	0.025	1.001	0.000	0.022
PF-LC2-B1	0.005	0.194	0.022	0.868	0.001	0.034
PF-LC2-B2	0.003	0.135	0.006	0.230	0.000	0.018
PF-LC2-B3	0.004	0.142	0.018	0.715	0.000	0.023
PF-HC1-C1	0.027	1.061	0.032	1.257	0.006	0.317
PF-HC1-C2	0.025	0.990	0.031	1.242	0.005	0.246
PF-HC1-C3	0.030	1.191	0.031	1.256	0.004	0.221
PF-HC1-B1	0.028	1.091	0.026	1.025	0.004	0.185
PF-HC1-B2	0.018	0.722	0.019	0.747	0.003	0.136
PF-HC1-B3	0.024	0.964	0.021	0.838	0.002	0.119
PF-HC2-C1	1.376	54.414	0.628	24.835	0.015	0.732
PF-HC2-C2	1.173	46.687	0.523	20.828	0.022	1.078
PF-HC2-C3	1.145	45.347	0.848	33.600	0.023	1.126

Code	Cd					
	F1		F2		F3	
	mg/L	**mg/kg**	**mg/L**	**mg/kg**	**mg/L**	**mg/kg**
PF-HC2-B1	0.187	7.413	0.143	5.663	0.026	1.268
PF-HC2-B2	0.198	7.797	0.185	7.273	0.015	0.759
PF-HC2-B3	0.175	6.953	0.119	4.741	0.012	0.586
MT-LC1-C1	0.004	0.170	0.002	0.094	0.000	0.015
MT-LC1-C2	0.004	0.174	0.002	0.097	0.000	0.021
MT-LC1-C3	0.006	0.222	0.004	0.138	0.000	0.013
MT-LC1-B1	0.009	0.360	0.006	0.223	0.001	0.041
MT-LC1-B2	0.010	0.409	0.007	0.267	0.001	0.039
MT-LC1-B3	0.011	0.450	0.008	0.311	0.001	0.039
MT-LC2-C1	0.024	0.951	0.020	0.783	0.006	0.320
MT-LC2-C2	0.027	1.054	0.023	0.890	0.006	0.298
MT-LC2-C3	0.021	0.814	0.018	0.703	0.003	0.128
MT-LC2-B1	0.006	0.228	0.005	0.190	0.001	0.027
MT-LC2-B2	0.009	0.339	0.006	0.233	0.001	0.038
MT-LC2-B3	0.007	0.271	0.005	0.194	0.001	0.028
MT-HC1-C1	0.015	0.597	0.026	1.022	0.007	0.370
MT-HC1-C2	0.019	0.769	0.023	0.919	0.006	0.287
MT-HC1-C3	0.026	1.056	0.023	0.909	0.005	0.261
MT-HC1-B1	0.017	0.652	0.015	0.601	0.004	0.184
MT-HC1-B2	0.016	0.645	0.016	0.620	0.003	0.158
MT-HC1-B3	0.020	0.777	0.019	0.773	0.004	0.210
MT-HC2-C1	0.017	0.681	0.031	1.248	0.019	0.950
MT-HC2-C2	0.019	0.747	0.026	1.058	0.019	0.964
MT-HC2-C3	0.020	0.813	0.025	0.999	0.019	0.956
MT-HC2-B1	0.021	0.830	0.038	1.525	0.013	0.627
MT-HC2-B2	0.023	0.910	0.035	1.392	0.010	0.475
MT-HC2-B3	0.021	0.818	0.035	1.403	0.013	0.629

Table A-4: Zn fraction for field experiment

Code	Zn					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
BG-LC1-C1	0.123	4.840	0.182	7.195	0.303	14.921
BG-LC1-C2	0.109	4.340	0.176	6.992	0.276	13.709
BG-LC1-C3	0.121	4.755	0.169	6.646	0.299	14.708
BG-LC1-B1	0.107	4.243	0.155	6.158	0.263	13.045
BG-LC1-B2	0.160	6.366	0.532	21.146	0.454	22.578
BG-LC1-B3	0.105	4.154	0.142	5.650	0.279	13.832
BG-LC2-C1	1.720	68.200	2.816	111.657	1.154	57.197
BG-LC2-C2	1.740	68.897	3.788	149.990	1.158	57.315
BG-LC2-C3	1.256	49.644	1.419	56.079	1.150	56.840
BG-LC2-B1	0.109	4.333	0.217	8.599	0.384	19.048
BG-LC2-B2	0.084	3.321	0.234	9.262	0.343	16.972
BG-LC2-B3	0.103	4.071	0.217	8.624	0.372	18.491
BG-HC1-C1	1.807	71.906	3.391	134.938	0.712	35.396
BG-HC1-C2	1.516	60.159	5.488	217.778	1.452	72.024
BG-HC1-C3	1.741	69.142	3.184	126.450	0.711	35.291
BG-HC1-B1	0.629	25.103	1.352	53.940	0.462	23.045
BG-HC1-B2	1.470	58.368	2.415	95.890	0.528	26.201
BG-HC1-B3	0.463	18.335	0.953	37.776	0.370	18.341
BG-HC2-C1	17.079	670.685	23.985	941.881	5.690	279.285
BG-HC2-C2	25.845	1026.002	34.090	1353.315	3.574	177.362
BG-HC2-C3	24.760	974.611	39.725	1563.669	4.996	245.813
BG-HC2-B1	5.148	205.345	10.368	413.562	2.108	105.106
BG-HC2-B2	4.985	198.368	13.660	543.573	2.416	120.175
BG-HC2-B3	4.681	185.256	10.710	423.907	1.988	98.333
OA-LC1-C1	0.135	5.362	0.186	7.411	0.305	15.218
OA-LC1-C2	0.115	4.572	0.164	6.540	0.376	18.733
OA-LC1-C3	0.111	4.394	0.165	6.536	0.291	14.375
OA-LC1-B1	0.182	7.257	0.285	11.375	0.371	18.563
OA-LC1-B2	0.328	13.091	0.473	18.867	0.438	21.849
OA-LC1-B3	0.325	12.872	0.523	20.722	0.458	22.676
OA-LC2-C1	1.711	67.951	3.655	145.155	1.095	54.359
OA-LC2-C2	2.782	109.895	2.845	112.384	1.007	49.723
OA-LC2-C3	0.666	26.242	1.261	49.695	0.867	42.724
OA-LC2-B1	0.137	5.419	0.254	10.087	0.390	19.368
OA-LC2-B2	0.075	2.982	0.244	9.675	0.300	14.856
OA-LC2-B3	0.140	5.500	0.196	7.735	0.364	17.918
OA-HC1-C1	2.300	91.506	5.187	206.366	1.305	64.900
OA-HC1-C2	2.927	116.590	4.405	175.463	1.011	50.339
OA-HC1-C3	2.503	99.365	4.027	159.865	0.914	45.360
OA-HC1-B1	0.811	31.998	3.948	155.770	0.808	39.850
OA-HC1-B2	0.521	20.778	1.143	45.601	0.415	20.686
OA-HC1-B3	0.688	27.430	1.405	56.032	0.429	21.406
OA-HC2-C1	22.666	904.469	33.082	1320.112	4.519	225.419
OA-HC2-C2	13.552	537.991	28.196	1119.333	4.162	206.506
OA-HC2-C3	15.785	774.534	27.916	1369.774	3.102	190.242
OA-HC2-B1	5.975	235.979	12.620	498.420	2.382	117.595

Code	Zn					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
OA-HC2-B2	2.934	116.339	11.525	457.069	2.200	109.062
OA-HC2-B3	4.769	187.904	11.500	453.113	2.247	110.643
VG-LC1-C1	0.178	7.084	0.200	7.970	0.297	14.832
VG-LC1-C2	0.152	6.088	0.181	7.224	0.295	14.755
VG-LC1-C3	0.166	6.633	0.193	7.690	0.315	15.687
VG-LC1-B1	0.344	13.543	0.441	17.353	0.431	21.213
VG-LC1-B2	0.584	23.241	0.476	18.942	0.404	20.069
VG-LC1-B3	0.167	6.643	0.508	20.183	0.456	22.626
VG-LC2-C1	1.640	65.131	2.747	109.095	1.031	51.181
VG-LC2-C2	1.335	52.976	2.356	93.492	0.888	44.058
VG-LC2-C3	1.580	62.998	5.555	221.491	0.751	37.440
VG-LC2-B1	0.129	5.143	0.238	9.514	0.341	17.047
VG-LC2-B2	0.122	4.837	0.235	9.356	0.337	16.741
VG-LC2-B3	0.136	5.437	0.258	10.291	0.355	17.710
VG-HC1-C1	2.500	99.167	4.636	183.895	1.194	59.203
VG-HC1-C2	2.991	117.779	4.350	171.294	1.070	52.668
VG-HC1-C3	2.036	80.858	3.571	141.819	0.806	40.007
VG-HC1-B1	0.715	28.410	1.232	48.967	0.410	20.380
VG-HC1-B2	0.600	23.843	1.183	47.010	0.424	21.061
VG-HC1-B3	0.382	15.252	1.356	54.099	0.434	21.644
VG-HC2-C1	18.124	723.385	35.175	1403.911	5.748	286.769
VG-HC2-C2	21.847	860.626	32.473	1279.220	3.887	191.407
VG-HC2-C3	22.400	888.008	32.452	1286.501	4.509	223.459
VG-HC2-B1	2.148	85.218	10.555	418.849	3.525	174.851
VG-HC2-B2	6.185	246.611	12.150	484.450	2.707	134.918
VG-HC2-B3	4.791	190.346	9.770	388.161	2.314	114.894
PF-LC1-C1	0.188	7.446	0.331	13.132	0.248	12.307
PF-LC1-C2	0.230	9.064	0.406	16.021	0.260	12.850
PF-LC1-C3	0.217	8.629	0.372	14.781	0.276	13.717
PF-LC1-B1	0.231	9.178	0.473	18.817	0.298	14.822
PF-LC1-B2	0.546	21.527	0.745	29.404	0.342	16.839
PF-LC1-B3	0.470	18.713	0.874	34.802	0.333	16.590
PF-LC2-C1	1.617	64.294	0.255	10.119	0.906	45.030
PF-LC2-C2	2.299	91.466	0.425	16.913	0.637	31.699
PF-LC2-C3	0.359	14.354	0.857	34.246	0.417	20.804
PF-LC2-B1	0.166	6.552	0.226	8.915	0.345	16.972
PF-LC2-B2	0.113	4.451	0.199	7.844	0.358	17.694
PF-LC2-B3	0.132	5.240	0.210	8.329	0.361	17.889
PF-HC1-C1	3.009	119.952	4.754	189.516	0.871	43.407
PF-HC1-C2	2.793	111.054	3.998	158.966	0.720	35.790
PF-HC1-C3	2.110	84.299	3.371	134.678	0.714	35.662
PF-HC1-B1	1.813	71.168	2.767	108.616	0.589	28.896
PF-HC1-B2	0.617	24.670	1.288	51.499	0.407	20.357
PF-HC1-B3	0.866	34.182	1.632	64.417	0.549	27.062
PF-HC2-C1	18.491	731.014	18.403	727.535	2.478	122.455
PF-HC2-C2	19.488	775.642	30.324	1206.925	3.350	166.642
PF-HC2-C3	19.915	788.713	36.078	1428.832	5.030	248.985
PF-HC2-B1	6.540	259.010	24.935	987.525	3.307	163.688

Code	Zn					
	F1		F2		F3	
	mg/L	mg/kg	mg/L	mg/kg	mg/L	mg/kg
PF-HC2-B2	6.450	254.137	11.970	471.631	2.027	99.833
PF-HC2-B3	5.095	202.665	9.505	378.083	1.719	85.446
MT-LC1-C1	0.168	6.635	0.276	10.869	0.424	20.915
MT-LC1-C2	0.156	6.211	0.284	11.312	0.430	21.445
MT-LC1-C3	0.208	8.160	0.408	16.048	0.432	21.210
MT-LC1-B1	0.452	17.917	0.732	28.974	0.618	30.599
MT-LC1-B2	0.466	18.581	0.846	33.717	0.583	29.071
MT-LC1-B3	0.636	25.248	1.107	43.981	0.637	31.650
MT-LC2-C1	1.610	63.398	2.628	103.485	1.020	50.207
MT-LC2-C2	2.011	78.940	3.046	119.568	0.963	47.228
MT-LC2-C3	0.798	31.683	1.271	50.437	0.639	31.677
MT-LC2-B1	0.115	4.582	0.220	8.766	0.310	15.426
MT-LC2-B2	0.153	6.024	0.243	9.565	0.366	18.021
MT-LC2-B3	0.103	4.116	0.191	7.625	0.332	16.509
MT-HC1-C1	2.599	103.361	4.173	165.957	1.446	71.883
MT-HC1-C2	2.561	102.113	3.399	135.526	1.298	64.693
MT-HC1-C3	2.213	88.449	3.304	132.054	1.286	64.249
MT-HC1-B1	1.185	46.626	1.826	71.847	1.001	49.233
MT-HC1-B2	0.547	21.763	0.990	39.383	0.787	39.154
MT-HC1-B3	0.838	33.356	1.443	57.410	0.828	41.183
MT-HC2-C1	18.540	738.351	31.270	1245.321	5.060	251.892
MT-HC2-C2	11.500	459.632	35.570	1421.663	5.650	282.274
MT-HC2-C3	17.580	700.259	34.690	1381.796	5.600	278.829
MT-HC2-B1	5.383	214.505	10.340	412.034	2.855	142.210
MT-HC2-B2	3.060	120.591	6.915	272.512	2.213	109.015

Appendix B
Mass and Cd and Zn concentration of rice plant parts

Table B-1: Mass and Cd and Zn concentration of rice plant parts

Code	Wet W.	Dry W.	Cd		Zn	
			ug/L	mg/kg	mg/L	mg/kg
VG-C-R1	0.4	0.2	1.079	0.127	10.833	1272.674
VG-C-R2	0.4	0.05	1.674	1.556	1.448	1345.260
VG-C-R3	1.3	0.5	1.018	0.129	6.135	775.993
VG-C-R4	1.3	0.1	0.637	0.111	7.083	1229.688
VG-C-R5	3.2	1.2	10.050	0.666	12.291	814.513
VG-O1-1-R1	7.6	2.1	22.100	1.462	13.350	883.053
VG-O1-1-R2	2.4	1.1	26.990	1.791	9.350	620.603
VG-O1-1-R3	0.6	0.2	13.490	2.017	5.765	861.992
VG-O1-1-R4	3.4	0.6	0.448	0.041	11.740	1061.867
VG-O1-1-R5	1.6	0.7	0.616	0.045	10.790	792.101
VG-O1-2-R1	3.7	1.3	20.590	1.366	12.155	806.676
VG-O1-2-R2	1.4	1.3	0.413	0.027	13.890	920.965
VG-O1-2-R3	4.0	1.5	1.264	0.084	14.330	948.379
VG-O1-2-R4	0.8	0.2	1.598	0.124	12.930	1007.009
VG-O1-2-R5	1.2	0.2	0.758	0.069	9.365	849.510
VG-O1-3-R1	4.7	1.3	1.122	0.074	15.705	1039.791
VG-O1-3-R2	7.0	2.3	0.684	0.045	14.290	948.242
VG-O1-3-R3	4.0	1.4	0.276	0.018	10.590	701.696
VG-O1-3-R4	1.8	0.6	0.328	0.030	8.800	795.948
VG-O1-3-R5	5.2	1.9	0.224	0.015	11.900	791.644
VG-O2-R1	0.6	0.2	0.216	0.039	4.065	731.115
VG-O2-R2	1.1	0.3	0.419	0.100	4.161	993.553
VG-O2-R3	2.3	0.3	0.160	0.043	3.278	882.131
VG-O2-R4	1.5	0.4	0.172	0.019	6.635	728.640
VG-O2-R5	2.1	0.9	14.890	1.098	12.060	889.249
VG-C-T1	1.3	0.5	18.141	1.715	0.539	50.946
VG-C-T2	0.5	0.05	14.360	8.853	0.287	176.757
VG-C-T3	5.8	2	12.460	0.826	1.306	86.547
VG-C-T4	4.7	0.7	19.660	1.305	1.887	125.299
VG-C-T5	19.2	5.7	15.330	1.020	1.286	85.528
VG-O1-1-T1	47.9	1.8	28.560	1.887	1.357	89.654
VG-O1-1-T2	9.6	3.4	21.050	1.402	1.282	85.364
VG-O1-1-T3	5.6	1.6	21.530	1.425	1.555	102.953
VG-O1-1-T4	10.3	3.4	26.790	1.782	1.339	89.053
VG-O1-1-T5	5.8	1.6	14.650	0.973	1.144	75.973
VG-O1-2-T1	19.9	5.6	11.990	0.794	0.926	61.304
VG-O1-2-T2	17.7	4.6	18.410	1.220	1.078	71.419
VG-O1-2-T3	14.9	3.9	15.240	1.008	0.935	61.853
VG-O1-2-T4	5.1	1.6	19.160	1.266	1.181	78.036
VG-O1-2-T5	5.1	0.9	20.050	1.333	1.123	74.687
VG-O1-3-T1	32.7	6.9	19.560	1.292	1.049	69.314
VG-O1-3-T2	31.7	7.6	15.100	1.001	0.944	62.599
VG-O1-3-T3	22.9	5.9	14.440	0.959	0.955	63.435

Code	Wet W.	Dry W.	Cd		Zn	
			ug/L	mg/kg	mg/L	mg/kg
VG-O1-3-T4	9.6	2.7	15.710	1.047	1.026	68.364
VG-O1-3-T5	15.4	4.4	15.160	1.009	0.817	54.317
VG-O2-T1	2.2	0.7	21.160	1.408	0.869	57.811
VG-O2-T2	6.9	1.8	27.070	1.803	1.621	107.952
VG-O2-T3	2.1	0.3	6.652	0.849	0.391	49.860
VG-O2-T4	4.2	0.9	17.870	1.180	1.066	70.363
VG-O2-T5	10.4	2.5	9.322	0.619	0.790	52.457
PF-C-R1	3.0	1.1	0.628	0.042	12.606	834.503
PF-C-R2	7.7	4.4	2.189	0.144	15.285	1006.254
PF-C-R3	19.5	2.4	0.972	0.064	12.417	821.447
PF-C-R4	3.2	1.7	7.081	0.466	14.766	972.727
PF-C-R5	3.7	1.8	19.550	1.301	16.035	1066.724
PF-O1-1-R1	0.5	0.1	1.327	0.088	13.568	896.406
PF-O1-1-R2	1.9	0.6	0.951	0.063	12.730	843.381
PF-O1-1-R3	1.1	0.3	0.920	0.071	15.915	1219.727
PF-O1-1-R4	0.7	0.1	0.233	0.025	8.520	928.509
PF-O1-1-R5	3.7	1.7	1.181	0.078	14.920	983.650
PF-O1-2-R1	8.8	3.4	4.792	0.318	26.615	1764.920
PF-O1-2-R2	4.3	2.3	17.480	1.160	14.815	983.209
PF-O1-2-R3	1.8	1.1	0.329	0.025	10.955	841.010
PF-O1-2-R4	2.2	0.9	0.356	0.023	13.300	876.730
PF-O1-2-R5	6.6	4	3.073	0.203	24.605	1621.951
PF-O1-3-R1	-	-	-	-	-	-
PF-O1-3-R2	3.6	1.5	18.550	1.231	16.415	1089.106
PF-O1-3-R3	13.6	9.3	9.723	0.641	20.340	1341.689
PF-O1-3-R4	2.9	1.1	22.100	1.460	11.370	751.189
PF-O1-3-R5	-	-	-	-	-	-
PF-O2-R1	2.6	1.2	13.970	0.927	12.920	857.332
PF-O2-R2	1.4	0.7	0.188	0.030	6.875	1098.243
PF-O2-R3	4.8	2.1	10.240	0.682	9.311	619.742
PF-O2-R4	-	-	-	-	-	-
PF-O2-R5	3.7	1.9	11.140	0.741	14.480	963.022
PF-C-T1	16.4	8.4	9.469	0.631	0.957	63.793
PF-C-T2	39.5	19.3	14.500	0.965	0.916	60.931
PF-C-T3	14.0	7.5	6.739	0.445	0.594	39.214
PF-C-T4	21.5	12.9	11.390	0.753	0.824	54.440
PF-C-T5	20.1	9.6	12.740	0.845	0.921	61.085
PF-O1-1-T1	2.2	1.3	15.980	1.059	1.687	111.840
PF-O1-1-T2	12.8	4.4	9.391	0.619	0.803	52.911
PF-O1-1-T3	4.6	2.4	9.884	0.651	0.639	42.097
PF-O1-1-T4	5.9	2.4	7.872	0.522	0.651	43.122
PF-O1-1-T5	39.8	16.9	15.940	1.056	-	0.000
PF-O1-2-T1	80.4	22	16.960	1.127	0.653	43.420
PF-O1-2-T2	21.5	11.1	7.358	0.489	1.321	87.821
PF-O1-2-T3	8.6	2.3	10.460	0.690	0.624	41.204
PF-O1-2-T4	32.4	16.2	6.680	0.443	0.931	61.714
PF-O1-2-T5	34.9	16.8	15.310	1.014	0.525	34.773
PF-O1-3-T1	17.9	8.6	9.637	0.639	0.963	63.902
PF-O1-3-T2	24.5	12	13.590	0.903	0.654	43.462
PF-O1-3-T3	51.3	22.4	10.800	0.719	1.006	67.004
PF-O1-3-T4	9.9	4.7	6.501	0.432	0.675	44.847
PF-O1-3-T5	-	-	-	-	-	-
PF-O2-T1	11.0	5	12.630	0.840	0.670	44.560

Code	Wet W.	Dry W.	Cd		Zn	
			ug/L	mg/kg	mg/L	mg/kg
PF-O2-T2	2.3	1.1	12.710	0.837	0.768	50.573
PF-O2-T3	15.2	4.3	10.810	0.716	0.562	37.204
PF-O2-T4	-	-	-	-	-	-
PF-O2-T5	28.8	3.7	11.360	0.752	0.506	33.501
PF-C-P1	2.1	1.2	50.000	3.317	0.637	42.251
PF-C-P2	4.5	2.7	50.000	3.325	1.138	75.685
PF-C-P3	-	-	-	-	-	-
PF-C-P4	4.1	3	50.000	3.323	0.724	48.119
PF-C-P5	-	-	-	-	-	-
PF-O1-1-P1	-	-	-	-	-	-
PF-O1-1-P2	0.8	0.3	1.882	0.336	0.261	46.502
PF-O1-1-P3	-	-	-	-	-	-
PF-O1-1-P4	0.4	0.3	0.149	0.033	0.590	129.617
PF-O1-1-P5	5.5	2.9	17.960	1.194	0.780	51.841
PF-O1-2-P1	13.3	7.3	14.520	0.966	0.439	29.222
PF-O1-2-P2	2.2	1.8	1.925	0.128	0.572	38.076
PF-O1-2-P3	-	-	-	-	-	-
PF-O1-2-P4	1.5	0.7	2.593	0.172	0.540	35.861
PF-O1-2-P5	5.9	3.4	10.770	0.712	0.625	41.362
PF-O1-3-P1	1.2	0.7	6.297	0.538	0.482	41.218
PF-O1-3-P2	1.6	1.2	15.590	1.038	0.827	55.027
PF-O1-3-P3	10.1	6.4	7.831	0.518	0.713	47.136
PF-O1-3-P4	0.7	0.3	0.496	0.098	0.209	41.482
PF-O1-3-P5	-	-	-	-	-	-
PF-O2-P1	0.7	0.4	2.483	0.381	0.408	62.696
PF-O2-P2	-	-	-	-	-	-
PF-O2-P3	2.2	0.3	3.467	0.390	0.266	29.944
PF-O2-P4	-	-	-	-	-	-
PF-O2-P5	3.0	2.3	8.332	0.553	0.678	44.995
MT-C-R1	8.0	1.7	20.260	1.338	12.498	825.604
MT-C-R2	16.9	1.6	26.910	1.785	9.462	627.787
MT-C-R3	12.4	3.4	16.700	1.112	15.060	1002.396
MT-C-R4	3.8	2	20.040	1.325	12.732	841.841
MT-C-R5	3.7	1.1	19.740	1.307	8.601	569.376
MT-O1-1-R1	3.4	0.8	19.850	1.942	13.530	1323.616
MT-O1-1-R2	12.4	2.2	18.735	1.243	25.205	1671.641
MT-O1-1-R3	5.8	1.5	18.230	1.210	19.080	1265.924
MT-O1-1-R4	17.1	3.3	15.842	1.047	22.780	1504.822
MT-O1-1-R5	6.4	1.8	16.910	1.122	17.320	1149.303
MT-O1-2-R1	4.7	2.6	16.020	1.065	18.250	1213.270
MT-O1-2-R2	16.1	2.8	15.870	1.048	17.570	1160.502
MT-O1-2-R3	18.7	3.4	17.750	1.175	16.465	1090.109
MT-O1-2-R4	1.7	0.7	19.600	2.151	7.255	796.378
MT-O1-2-R5	11.4	1.6	16.250	1.072	12.875	849.611
MT-O1-3-R1	4.1	2.1	13.560	0.902	18.090	1203.753
MT-O1-3-R2	19.5	4.1	13.640	0.905	23.045	1528.183
MT-O1-3-R3	19.8	3.5	17.270	1.149	15.600	1037.924
MT-O1-3-R4	2.1	0.2	18.910	3.101	10.890	1785.831
MT-O1-3-R5	-	-	-	-	-	-
MT-O2-R1	21.1	2.7	24.700	1.640	16.400	1089.122
MT-O2-R2	2.3	0.6	21.900	3.008	7.933	1089.698
MT-O2-R3	1.7	1.7	13.710	0.909	13.730	910.598
MT-O2-R4	9.6	1.3	15.690	1.044	13.810	918.585

Code	Wet W.	Dry W.	Cd		Zn	
			ug/L	mg/kg	mg/L	mg/kg
MT-O2-R5	5.4	4.7	16.840	1.110	21.400	1410.493
MT-C-T1	7.7	6.3	21.300	1.417	0.910	60.535
MT-C-T2	9.1	5.2	13.160	0.871	0.837	55.367
MT-C-T3	45.7	23.4	25.850	1.709	1.457	96.311
MT-C-T4	25.1	16.6	0.877	0.058	0.673	44.556
MT-C-T5	20.9	10.3	0.412	0.027	1.132	75.086
MT-O1-1-T1	18.8	5.3	8.535	0.569	0.521	34.672
MT-O1-1-T2	26.3	8.2	18.650	1.240	0.875	58.179
MT-O1-1-T3	21.3	6.7	22.720	1.511	1.384	92.021
MT-O1-1-T4	77.9	20.5	26.900	1.773	1.402	92.395
MT-O1-1-T5	15.7	6	8.275	0.549	0.539	35.695
MT-O1-2-T1	21.4	8.4	6.513	0.430	0.385	25.436
MT-O1-2-T2	41.9	10.8	21.850	1.447	1.030	68.212
MT-O1-2-T3	52.8	15	13.630	0.905	0.902	59.896
MT-O1-2-T4	5.0	1.5	9.466	0.631	0.596	39.728
MT-O1-2-T5	20.5	5.1	16.860	1.122	0.698	46.426
MT-O1-3-T1	26.1	11.5	7.122	0.473	0.449	29.810
MT-O1-3-T2	35.1	14	23.650	1.568	1.287	85.334
MT-O1-3-T3	59.0	13	12.300	0.819	0.664	44.211
MT-O1-3-T4	18.2	7.5	19.360	1.282	1.219	80.696
MT-O1-3-T5	21.3	5.2	18.520	1.229	1.224	81.210
MT-O2-T1	41.6	11.7	18.790	1.250	0.806	53.598
MT-O2-T2	7.0	2.7	10.290	0.684	0.718	47.708
MT-O2-T3	16.6	6.7	21.090	1.396	1.464	96.915
MT-O2-T4	13.2	3.9	15.410	1.027	1.064	70.886
MT-O2-T5	20.6	17.7	24.710	1.636	0.955	63.223
MT-C-G1	12.6	4.8	2.299	0.153	0.321	21.375
MT-C-G2	5.4	1.8	2.581	0.212	0.864	70.870
MT-C-G3	15.6	7.6	9.460	0.627	0.759	50.325
MT-C-G4	18.0	7	4.885	0.324	0.463	30.728
MT-C-G5	6.4	2.1	4.791	0.317	0.552	36.576
MT-O1-1-G1	6.0	3.7	2.179	0.145	0.306	20.283
MT-O1-1-G2	5.9	4	4.880	0.325	0.472	31.438
MT-O1-1-G3	2.8	1.4	3.077	0.204	0.573	37.877
MT-O1-1-G4	13.2	7.6	12.140	0.805	0.603	39.967
MT-O1-1-G5	6.4	3.6	1.041	0.069	0.307	20.391
MT-O1-2-G1	11.8	8.2	1.146	0.076	0.355	23.568
MT-O1-2-G2	7.4	5	11.390	0.756	0.496	32.893
MT-O1-2-G3	11.2	6	2.877	0.191	0.573	38.090
MT-O1-2-G4	2.1	0.8	0.346	0.150	0.116	50.565
MT-O1-2-G5	3.7	2.1	2.403	0.160	0.348	23.077
MT-O1-3-G1	11.8	8.4	1.444	0.096	0.359	23.870
MT-O1-3-G2	10.3	6.5	10.900	0.725	0.608	40.443
MT-O1-3-G3	16.2	7.1	1.164	0.077	0.398	26.469
MT-O1-3-G4	1.6	0.8	7.667	0.620	0.598	48.382
MT-O1-3-G5	-	-	-	-	-	-
MT-O2-G1	8.4	5.2	6.319	0.418	0.417	27.636
MT-O2-G2	0.5	0.3	2.989	0.322	0.359	38.598
MT-O2-G3	3.3	1.6	4.116	0.273	0.471	31.282
MT-O2-G4	4.5	2.6	3.707	0.246	0.304	20.207
MT-O2-G5	37.1	15.3	11.120	0.738	0.369	24.469

Table B-2: Mass and Cd and Zn concentration of rice plant parts for field experiment

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
VG-LC1-C-R1	45.5	6.6	0.004	0.2655	1.677	111.3102
VG-LC1-C-R2	40.9	5.8	0.009	0.5961	2.142	141.8731
VG-LC1-C-R3	42.0	5.9	0.008	0.5270	2.095	138.0105
VG-LC1-C-R4	68.7	8.8	0.004	0.2637	0.968	63.8102
VG-LC1-C-R5	54.2	8.4	0.008	0.5318	1.003	66.6711
VG-LC1-O-R1	63.8	8.4	0.012	0.7941	1.816	120.1694
VG-LC1-O-R2	66.7	9.3	0.007	0.4643	1.101	73.0300
VG-LC1-O-R3	76.1	12.1	0.016	1.0574	1.305	86.2411
VG-LC1-O-R4	72.8	9.4	0.028	1.8632	2.008	133.6172
VG-LC1-O-R5	51.5	7.0	0.012	0.7954	1.383	91.6744
VG-LC2-C-R1	46.9	5.5	0.018	1.1864	1.763	116.2009
VG-LC2-C-R2	92.6	11.0	0.017	1.1270	2.041	135.3089
VG-LC2-C-R3	52.4	10.9	0.025	1.6523	1.748	115.5321
VG-LC2-C-R4	75.9	11.2	0.009	0.5927	1.107	72.8961
VG-LC2-C-R5	52.2	8.9	0.008	0.5311	1.017	67.5209
VG-LC2-O-R1	66.6	6.7	0.005	0.3326	1.158	77.0254
VG-LC2-O-R2	64.1	6.6	0.004	0.2655	1.255	83.3001
VG-LC2-O-R3	64.5	10.2	0.006	0.3986	1.144	75.9931
VG-LC2-O-R4	69.3	7.8	0.009	0.5983	1.307	86.8900
VG-LC2-O-R5	83.3	10.1	0.005	0.3317	1.384	91.8015
VG-HC1-C-R1	39.3	7.1	0.142	9.4440	2.700	179.5690
VG-HC1-C-R2	40.1	8.6	0.073	4.8531	2.210	146.9220
VG-HC1-C-R3	40.2	8.8	0.223	14.7565	2.360	156.1673
VG-HC1-C-R4	41.0	8.9	0.151	9.9881	2.280	150.8136
VG-HC1-C-R5	34.3	6.9	0.119	7.9196	2.250	149.7404
VG-HC1-O-R1	37.4	5.5	0.216	14.2311	2.110	139.0170
VG-HC1-O-R2	52.8	9.1	0.131	8.6732	2.520	166.8432
VG-HC1-O-R3	46.9	9.5	0.190	12.5745	1.940	128.3918
VG-HC1-O-R4	34.1	7.1	0.170	11.2034	1.860	122.5781
VG-HC1-O-R5	38.6	5.7	0.201	13.2568	2.060	135.8660
VG-HC2-C-R1	45.8	5.4	0.642	42.6351	7.780	516.6689
VG-HC2-C-R2	24.1	3.0	0.183	12.1272	6.800	450.6296
VG-HC2-C-R3	29.4	4.1	0.210	13.8285	6.850	451.0734
VG-HC2-C-R4	54.6	7.0	0.637	42.2470	7.290	483.4859
VG-HC2-C-R5	37.1	5.2	0.194	12.7968	6.850	451.8470
VG-HC2-O-R1	47.3	6.2	0.184	12.1100	4.050	266.5526
VG-HC2-O-R2	38.4	5.5	0.070	4.6150	3.780	249.2089
VG-HC2-O-R3	42.8	5.5	0.291	19.2741	4.030	266.9228
VG-HC2-O-R4	46.4	5.9	0.235	15.5712	3.690	244.5004
VG-HC2-O-R5	60.2	9.3	0.177	11.7234	3.390	224.5331

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
VG-LC1-C-T1	126.8	26.7	0.0020	0.1327	0.704	46.7277
VG-LC1-C-T2	93.4	22.7	0.0005	0.0330	0.528	34.8021
VG-LC1-C-T3	84.6	18.8	0.0005	0.0330	0.533	35.2153
VG-LC1-C-T4	204.8	39.3	0.0005	0.0331	0.446	29.4751
VG-LC1-C-T5	134.1	27.2	0.0005	0.0330	0.439	28.9585
VG-LC1-O-T1	172.4	33.6	0.0005	0.0330	0.459	30.2241
VG-LC1-O-T2	163.3	33.0	0.0005	0.0331	0.459	30.3957
VG-LC1-O-T3	153.9	31.0	0.0005	0.0331	0.581	38.3893
VG-LC1-O-T4	130.8	22.7	0.0005	0.0330	0.470	31.0181
VG-LC1-O-T5	93.4	22.9	0.0005	0.0330	0.471	31.1220
VG-LC2-C-T1	273.4	42.5	0.0030	0.1988	0.582	38.5951
VG-LC2-C-T2	465.7	82.1	0.0030	0.1980	0.508	33.5094
VG-LC2-C-T3	203.9	39.3	0.0020	0.1325	0.658	43.5604
VG-LC2-C-T4	240.4	42.2	0.0005	0.0332	0.562	37.2811
VG-LC2-C-T5	164.0	35.2	0.0005	0.0330	0.444	29.2612
VG-LC2-O-T1	231.9	38.3	0.0005	0.0332	0.581	38.6278
VG-LC2-O-T2	160.0	28.1	0.0005	0.0329	0.570	37.5395
VG-LC2-O-T3	203.0	40.0	0.0005	0.0331	0.493	32.6755
VG-LC2-O-T4	216.9	35.5	0.0020	0.1317	0.589	38.7887
VG-LC2-O-T5	214.1	40.6	0.0005	0.0332	0.553	36.6578
VG-HC1-C-T1	206.0	37.6	0.076	5.0125	1.030	67.9330
VG-HC1-C-T2	219.6	43.5	0.109	7.2435	0.770	51.1696
VG-HC1-C-T3	151.2	32.8	0.134	8.8930	0.800	53.0926
VG-HC1-C-T4	185.0	41.7	0.195	12.9071	0.880	58.2473
VG-HC1-C-T5	173.8	36.0	0.192	12.7439	0.800	53.0997
VG-HC1-O-T1	106.5	21.8	0.170	11.2019	0.760	50.0791
VG-HC1-O-T2	177.6	35.9	0.127	8.4262	0.710	47.1072
VG-HC1-O-T3	111.4	26.2	0.072	4.7936	0.770	51.2650
VG-HC1-O-T4	144.8	31.8	0.202	13.3917	1.460	96.7913
VG-HC1-O-T5	100.3	25.5	0.080	5.3206	0.750	49.8803
VG-HC2-C-T1	125.8	23.6	0.227	15.0871	2.340	155.5231
VG-HC2-C-T2	110.4	20.0	0.194	12.8104	0.770	50.8452
VG-HC2-C-T3	143.8	28.2	0.035	2.3200	1.470	97.4413
VG-HC2-C-T4	142.2	26.7	0.117	7.7803	1.710	113.7119
VG-HC2-C-T5	182.4	32.0	0.060	3.9756	0.960	63.6099
VG-HC2-O-T1	158.5	28.8	0.155	10.3141	0.880	58.5574
VG-HC2-O-T2	151.6	28.3	0.181	11.9157	0.780	51.3496
VG-HC2-O-T3	154.4	27.8	0.086	5.6871	0.920	60.8385
VG-HC2-O-T4	132.1	25.6	0.157	10.4319	0.760	50.4983
VG-HC2-O-T5	261.6	47.3	0.132	8.7440	0.800	52.9942
PF-LC1-C-R1	74.7	13.8	0.003	0.1789	1.260	83.4437
PF-LC1-C-R2	46.2	10.5	0.004	0.2546	1.289	85.1050

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
PF-LC1-C-R3	54.2	11.8	0.024	1.6133	1.357	90.1661
PF-LC1-C-R4	88.8	26.5	0.002	0.1084	1.005	66.7685
PF-LC1-C-R5	88.4	10.8	0.002	0.1025	1.172	77.2985
PF-LC1-O-R1	89.4	15.1	0.014	0.9397	1.363	90.1336
PF-LC1-O-R2	108.4	15.1	0.003	0.2262	0.982	64.9808
PF-LC1-O-R3	69.6	10.8	0.004	0.2749	1.782	117.7792
PF-LC1-O-R4	79.2	15.3	0.005	0.3088	1.638	108.4625
PF-LC1-O-R5	74.0	9.1	0.002	0.1626	0.949	62.6469
PF-LC2-C-R1	157.3	28.9	0.016	1.0377	1.564	104.1001
PF-LC2-C-R2	231.5	28.9	0.035	2.3338	3.397	224.0765
PF-LC2-C-R3	87.7	14.4	0.003	0.2002	0.795	52.6692
PF-LC2-C-R4	167.3	23.8	0.003	0.2320	0.749	49.7279
PF-LC2-C-R5	133.7	22.0	0.005	0.3582	1.279	84.8031
PF-LC2-O-R1	105.7	14.0	0.002	0.1396	0.547	36.0792
PF-LC2-O-R2	215.6	39.0	0.004	0.2931	0.924	61.2179
PF-LC2-O-R3	70.2	10.9	0.006	0.3697	0.877	57.9992
PF-LC2-O-R4	96.3	12.4	0.004	0.2337	0.671	44.3452
PF-LC2-O-R5	117.1	20.9	0.002	0.1342	0.636	41.9889
PF-HC1-C-R1	132.3	16.0	0.004	0.2978	2.467	163.3558
PF-HC1-C-R2	154.4	27.2	0.032	2.1490	2.566	170.5663
PF-HC1-C-R3	99.5	15.1	0.006	0.3866	2.627	174.0427
PF-HC1-C-R4	162.4	23.0	0.005	0.3175	2.287	152.0612
PF-HC1-C-R5	144.7	19.5	0.018	1.2114	2.220	147.1953
PF-HC1-O-R1	131.1	18.1	0.005	0.3221	1.947	129.5065
PF-HC1-O-R2	101.8	16.0	0.016	1.0880	2.301	152.7483
PF-HC1-O-R3	105.3	13.8	0.023	1.5009	2.807	186.8344
PF-HC1-O-R4	109.1	12.9	0.005	0.3503	1.796	118.7674
PF-HC1-O-R5	96.1	15.6	0.018	1.1862	1.631	107.8418
PF-HC2-C-R1	92.9	18.3	1.885	125.3491	7.144	475.0632
PF-HC2-C-R2	78.6	12.4	0.030	1.9870	4.856	320.0211
PF-HC2-C-R3	62.1	13.8	0.652	43.4079	10.570	703.8221
PF-HC2-C-R4	71.9	12.5	0.866	57.3092	8.521	563.6328
PF-HC2-C-R5	182.7	20.7	1.383	91.8449	16.680	1107.7168
PF-HC2-O-R1	85.6	16.5	0.753	49.6113	5.467	360.1449
PF-HC2-O-R2	132.2	19.5	0.620	41.2320	5.097	339.0766
PF-HC2-O-R3	188.5	33.4	1.434	94.9292	7.221	478.0220
PF-HC2-O-R4	97.0	12.6	0.479	31.8587	4.729	314.5955
PF-HC2-O-R5	117.7	17.0	0.466	30.9796	4.155	276.5207
PF-LC1-C-T1	493.9	128.4	0.008	0.5321	0.854	56.8037
PF-LC1-C-T2	319.8	93.3	0.005	0.3326	0.691	45.9353
PF-LC1-C-T3	340.6	98.5	0.015	0.9919	1.146	75.7836
PF-LC1-C-T4	652.1	194.0	0.001	0.0330	0.514	33.8899

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
PF-LC1-C-T5	470.1	116.9	0.001	0.0664	0.458	30.4143
PF-LC1-O-T1	517.6	143.5	0.008	0.5295	0.803	53.1171
PF-LC1-O-T2	295.2	78.6	0.001	0.0662	0.458	30.2806
PF-LC1-O-T3	490.9	129.1	0.003	0.1983	0.820	54.2036
PF-LC1-O-T4	631.9	171.3	0.001	0.0661	0.543	35.8530
PF-LC1-O-T5	433.3	118.4	0.001	0.0329	0.266	17.5405
PF-LC2-C-T1	1045.7	272.0	0.002	0.1329	0.445	29.5415
PF-LC2-C-T2	1194.1	295.3	0.001	0.0661	0.502	33.1417
PF-LC2-C-T3	456.7	141.4	0.001	0.0663	0.491	32.5222
PF-LC2-C-T4	700.9	211.1	0.001	0.0333	0.407	27.1105
PF-LC2-C-T5	549.6	173.0	0.001	0.0662	0.410	27.1175
PF-LC2-O-T1	643.7	176.8	0.001	0.0329	0.370	24.3544
PF-LC2-O-T2	724.3	250.0	0.001	0.0330	0.428	28.2551
PF-LC2-O-T3	517.8	145.2	0.004	0.2636	0.476	31.3604
PF-LC2-O-T4	495.2	131.4	0.001	0.0662	0.573	37.9402
PF-LC2-O-T5	555.5	179.5	0.002	0.1317	0.513	33.7724
PF-HC1-C-T1	694.5	180.9	0.001	0.0662	0.516	34.1141
PF-HC1-C-T2	655.7	201.6	0.001	0.0658	0.625	41.1532
PF-HC1-C-T3	392.8	106.8	0.001	0.0664	0.670	44.5389
PF-HC1-C-T4	754.1	212.4	0.001	0.0665	0.532	35.3629
PF-HC1-C-T5	564.5	160.4	0.001	0.0330	0.453	29.9300
PF-HC1-O-T1	640.1	187.1	0.001	0.0663	0.540	35.8214
PF-HC1-O-T2	277.1	77.3	0.004	0.2639	0.947	62.4621
PF-HC1-O-T3	389.1	102.1	0.003	0.1993	0.839	55.7386
PF-HC1-O-T4	325.7	84.5	0.001	0.0662	0.571	37.8110
PF-HC1-O-T5	368.6	90.3	0.005	0.3333	0.902	60.1120
PF-HC2-C-T1	570.3	185.2	0.030	1.9957	1.507	100.2528
PF-HC2-C-T2	575.7	162.4	0.009	0.5979	0.773	51.3553
PF-HC2-C-T3	565.6	182.7	0.029	1.9308	1.340	89.2144
PF-HC2-C-T4	546.0	168.3	0.030	1.9868	1.138	75.3642
PF-HC2-C-T5	671.7	180.4	0.018	1.1927	1.059	70.1696
PF-HC2-O-T1	669.7	196.8	0.012	0.7974	0.733	48.6975
PF-HC2-O-T2	636.3	184.4	0.021	1.3894	0.691	45.7126
PF-HC2-O-T3	754.4	252.8	0.003	0.1989	1.085	71.9210
PF-HC2-O-T4	525.7	160.4	0.002	0.1317	0.695	45.7911
PF-HC2-O-T5	471.4	163.1	0.005	0.3298	0.516	34.0567
PF-LC1-C-P1	41.7	19.1	0.001	0.0660	0.402	26.5347
PF-LC1-C-P2	28.5	13.8	0.001	0.0660	0.343	22.6390
PF-LC1-C-P3	25.2	11.8	0.004	0.2660	0.478	31.8127
PF-LC1-C-P4	59.0	26.9	0.001	0.0331	0.352	23.2976
PF-LC1-C-P5	47.4	17.0	0.001	0.0330	0.383	25.2575
PF-LC1-O-P1	51.7	22.5	0.002	0.1329	0.410	27.2594

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
PF-LC1-O-P2	26.5	11.1	0.001	0.0330	0.340	22.4865
PF-LC1-O-P3	49.4	19.8	0.001	0.0659	0.437	28.8294
PF-LC1-O-P4	65.3	27.4	0.001	0.0331	0.434	28.7028
PF-LC1-O-P5	38.0	15.8	0.001	0.0331	0.408	26.9898
PF-LC2-C-P1	71.7	25.4	0.001	0.0332	0.350	23.2877
PF-LC2-C-P2	81.9	32.2	0.001	0.0331	0.426	28.1912
PF-LC2-C-P3	35.4	16.6	0.002	0.1319	0.497	32.7509
PF-LC2-C-P4	45.1	19.1	0.001	0.0333	0.435	28.9127
PF-LC2-C-P5	43.2	19.4	0.001	0.0331	0.358	23.6978
PF-LC2-O-P1	54.7	22.0	0.001	0.0331	0.364	24.0959
PF-LC2-O-P2	62.0	31.7	0.001	0.0332	0.424	28.1503
PF-LC2-O-P3	39.2	16.9	0.002	0.1320	0.377	24.8680
PF-LC2-O-P4	40.4	18.2	0.001	0.0331	0.409	27.0626
PF-LC2-O-P5	36.5	19.8	0.001	0.0662	0.434	28.7720
PF-HC1-C-P1	48.1	19.7	0.002	0.1327	0.426	28.2652
PF-HC1-C-P2	61.9	27.2	0.001	0.0333	0.408	27.1602
PF-HC1-C-P3	39.3	15.5	0.001	0.0663	0.611	40.5533
PF-HC1-C-P4	60.2	25.2	0.001	0.0662	0.493	32.6314
PF-HC1-C-P5	49.8	22.2	0.001	0.0664	0.460	30.5807
PF-HC1-O-P1	84.8	14.8	0.001	0.0333	0.316	21.0603
PF-HC1-O-P2	41.1	36.4	0.002	0.1320	0.479	31.5991
PF-HC1-O-P3	44.7	17.8	0.002	0.1332	0.484	32.2347
PF-HC1-O-P4	33.8	13.9	0.003	0.1997	0.474	31.5296
PF-HC1-O-P5	46.7	19.0	0.002	0.1324	0.465	30.7494
PF-HC2-C-P1	54.1	25.4	0.010	0.6650	0.581	38.6355
PF-HC2-C-P2	51.5	22.1	0.003	0.1983	0.498	32.9102
PF-HC2-C-P3	45.5	22.0	0.010	0.6616	0.746	49.3715
PF-HC2-C-P4	53.8	26.4	0.014	0.9292	0.616	40.9000
PF-HC2-C-P5	46.4	19.6	0.003	0.1987	0.424	28.0766
PF-HC2-O-P1	59.8	26.9	0.005	0.3293	0.478	31.4895
PF-HC2-O-P2	36.9	23.3	0.001	0.0660	0.440	29.0116
PF-HC2-O-P3	58.6	32.3	0.004	0.2636	0.421	27.7646
PF-HC2-O-P4	48.2	21.6	0.002	0.1325	0.359	23.8007
PF-HC2-O-P5	39.2	20.0	0.001	0.0659	0.397	26.1475
MT-LC1-C-R1	47.8	18.5	0.004	0.2480	1.157	77.0511
MT-LC1-C-R2	41.5	19.0	0.005	0.3252	1.177	84.4288
MT-LC1-C-R3	36.6	16.1	0.005	0.3521	1.459	98.5419
MT-LC1-C-R4	47.0	18.9	0.005	0.3169	0.840	55.3666
MT-LC1-C-R5	35.5	18.9	0.021	1.3880	1.300	86.5397
MT-LC1-O-R1	37.0	16.6	0.003	0.1785	1.405	92.8005
MT-LC1-O-R2	53.6	18.1	0.004	0.2554	1.092	72.3370
MT-LC1-O-R3	43.3	16.9	0.024	1.6088	2.398	158.8921

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
MT-LC1-O-R4	42.5	21.7	0.002	0.1084	1.727	114.7508
MT-LC1-O-R5	57.2	20.3	0.002	0.1026	1.387	91.5391
MT-LC2-C-R1	90.1	30.5	0.002	0.1032	2.669	176.9894
MT-LC2-C-R2	92.5	32.4	0.037	2.4723	1.875	123.7787
MT-LC2-C-R3	76.9	21.4	0.002	0.1656	1.515	100.6377
MT-LC2-C-R4	87.2	30.9	0.038	2.5220	0.866	57.6805
MT-LC2-C-R5	42.8	19.6	0.003	0.1703	0.777	51.4017
MT-LC2-O-R1	57.2	21.6	0.016	1.0367	0.658	43.7226
MT-LC2-O-R2	40.2	17.7	0.035	2.3427	1.043	69.0637
MT-LC2-O-R3	45.8	20.4	0.003	0.1991	1.256	82.7078
MT-LC2-O-R4	52.1	18.4	0.003	0.2324	0.927	61.6193
MT-LC2-O-R5	55.9	21.4	0.005	0.3560	1.148	75.6358
MT-HC1-C-R1	68.8	17.9	0.002	0.2106	1.663	165.6045
MT-HC1-C-R2	56.4	21.1	0.004	0.4419	1.512	151.0188
MT-HC1-C-R3	87.1	23.3	0.006	0.5581	1.571	156.9117
MT-HC1-C-R4	53.8	17.4	0.004	0.3514	1.388	138.0270
MT-HC1-C-R5	67.5	21.0	0.002	0.2011	1.464	144.7499
MT-HC1-O-R1	36.1	16.7	0.004	0.4476	1.218	121.2423
MT-HC1-O-R2	30.0	12.9	0.032	3.1934	1.159	114.4804
MT-HC1-O-R3	43.0	16.1	0.006	0.5780	1.638	162.2425
MT-HC1-O-R4	73.1	20.6	0.005	0.4708	1.200	118.3199
MT-HC1-O-R5	28.6	13.0	0.018	1.8004	1.371	135.1005
MT-HC2-C-R1	68.7	19.5	0.005	4.8217	6.885	685.6204
MT-HC2-C-R2	42.4	15.6	0.016	16.1925	7.056	697.0954
MT-HC2-C-R3	57.3	19.2	0.023	22.4691	5.436	541.6501
MT-HC2-C-R4	47.0	17.5	0.005	5.2498	5.268	522.1011
MT-HC2-C-R5	49.2	16.3	0.018	17.7553	6.780	671.0214
MT-HC2-O-R1	37.5	16.7	0.144	14.3055	2.932	290.4300
MT-HC2-O-R2	58.6	18.0	0.090	9.0082	2.354	234.8932
MT-HC2-O-R3	63.2	21.5	0.102	10.6605	3.063	319.5021
MT-HC2-O-R4	45.7	19.2	0.082	8.1635	1.894	189.2386
MT-HC2-O-R5	66.3	24.6	0.130	12.7332	3.462	339.8783
MT-LC1-C-T1	303.9	89.6	0.008	0.5377	1.023	67.7483
MT-LC1-C-T2	284.9	92.8	0.002	0.1609	0.876	57.6847
MT-LC1-C-T3	193.7	53.6	0.003	0.2161	1.087	71.8725
MT-LC1-C-T4	380.6	119.7	0.001	0.0542	0.721	47.9269
MT-LC1-C-T5	277.5	78.2	0.003	0.2122	0.910	60.1242
MT-LC1-O-T1	330.7	108.5	0.004	0.2371	1.579	104.2657
MT-LC1-O-T2	251.7	82.6	0.001	0.0708	0.655	43.1187
MT-LC1-O-T3	210.8	61.7	0.001	0.0647	0.956	63.4457
MT-LC1-O-T4	358.1	113.8	0.001	0.0891	0.860	57.1761
MT-LC1-O-T5	268.9	78.0	0.003	0.2015	0.248	16.4346

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
MT-LC2-C-T1	758.1	246.3	0.002	0.1154	0.594	39.4922
MT-LC2-C-T2	787.3	293.4	0.001	0.0462	0.637	42.4019
MT-LC2-C-T3	437.8	138.9	0.018	1.2201	0.829	55.1330
MT-LC2-C-T4	390.3	141.7	0.001	0.0350	0.514	34.2572
MT-LC2-C-T5	327.1	106.2	0.000	0.0141	0.406	27.4772
MT-LC2-O-T1	394.9	120.0	0.005	0.3282	0.509	33.7850
MT-LC2-O-T2	264.1	82.2	0.004	0.2526	0.790	52.3100
MT-LC2-O-T3	282.0	93.5	0.015	1.0003	1.005	66.5739
MT-LC2-O-T4	292.8	94.0	0.004	0.2964	0.645	42.5545
MT-LC2-O-T5	362.2	129.9	0.006	0.4253	0.759	50.4120
MT-HC1-C-T1	461.8	122.4	0.004	0.2605	0.673	44.6353
MT-HC1-C-T2	509.3	162.0	0.004	0.2903	0.741	49.3345
MT-HC1-C-T3	640.1	207.5	0.005	0.3307	0.872	57.6374
MT-HC1-C-T4	380.1	130.4	0.005	0.3000	0.705	46.7768
MT-HC1-C-T5	514.6	167.1	0.003	0.1913	0.788	52.4088
MT-HC1-O-T1	374.6	113.0	0.005	0.3406	0.890	59.3071
MT-HC1-O-T2	277.8	89.1	0.006	0.3879	0.878	58.0217
MT-HC1-O-T3	321.6	104.8	0.006	0.3667	0.876	58.2248
MT-HC1-O-T4	537.3	179.3	0.004	0.2576	0.750	49.8404
MT-HC1-O-T5	304.9	91.2	0.007	0.4762	0.884	58.5508
MT-HC2-C-T1	456.6	143.1	0.052	3.4427	1.808	119.8144
MT-HC2-C-T2	403.7	131.7	0.025	1.6487	1.336	88.8534
MT-HC2-C-T3	395.6	124.4	0.068	4.5080	2.067	136.3277
MT-HC2-C-T4	433.4	131.7	0.039	2.5884	1.368	90.2137
MT-HC2-C-T5	314.3	107.0	0.054	3.6046	1.838	122.0127
MT-HC2-O-T1	309.8	107.1	0.044	2.9463	1.157	76.8464
MT-HC2-O-T2	374.8	120.0	0.025	1.6239	1.010	66.8608
MT-HC2-O-T3	372.2	124.4	0.039	2.6081	1.065	70.8583
MT-HC2-O-T4	425.8	153.2	0.021	1.4053	1.066	70.3630
MT-HC2-O-T5	429.1	151.1	0.015	0.9859	0.910	59.9644
MT-LC1-C-G1	83.5	60.3	0.004	0.1919	0.323	16.1142
MT-LC1-C-G2	81.9	61.2	0.003	0.1540	0.278	13.8518
MT-LC1-C-G3	50.7	34.0	0.004	0.2155	0.350	17.3552
MT-LC1-C-G4	98.5	71.4	0.001	0.0519	0.304	15.1154
MT-LC1-C-G5	99.4	73.0	0.001	0.0477	0.282	14.0106
MT-LC1-O-G1	90.7	65.0	0.006	0.2746	0.315	15.6620
MT-LC1-O-G2	72.3	51.4	0.001	0.0471	0.260	12.9056
MT-LC1-O-G3	58.5	40.0	0.003	0.1623	0.295	14.7364
MT-LC1-O-G4	121.0	90.0	0.001	0.0660	0.261	12.9810
MT-LC1-O-G5	60.1	41.4	0.000	0.0115	0.250	12.4043
MT-LC2-C-G1	81.7	57.6	0.006	0.3002	0.353	17.5025
MT-LC2-C-G2	179.6	133.3	0.003	0.1624	0.350	17.3741

Code	Wet W.	Dry W.	Cd		Zn	
			mg/L	mg/kg	mg/L	mg/kg
MT-LC2-C-G3	92.3	67.1	0.007	0.3279	0.322	16.0602
MT-LC2-C-G4	131.6	97.7	0.001	0.0499	0.333	16.6567
MT-LC2-C-G5	65.9	47.2	0.003	0.1562	0.319	15.8190
MT-LC2-O-G1	101.1	75.7	0.002	0.0963	0.292	14.5661
MT-LC2-O-G2	64.5	47.7	0.002	0.0846	0.320	16.0150
MT-LC2-O-G3	74.2	52.8	0.008	0.3889	0.286	14.1829
MT-LC2-O-G4	92.0	68.6	0.005	0.2283	0.267	13.3050
MT-LC2-O-G5	91.8	70.4	0.004	0.1801	0.289	14.3204
MT-HC1-C-G1	91.2	66.7	0.004	0.2064	0.311	15.5233
MT-HC1-C-G2	117.5	87.7	0.004	0.1808	0.288	14.3642
MT-HC1-C-G3	124.8	94.9	0.004	0.1988	0.291	14.4441
MT-HC1-C-G4	107.5	81.0	0.003	0.1310	0.296	14.7623
MT-HC1-C-G5	129.1	98.0	0.004	0.1891	0.311	15.5312
MT-HC1-O-G1	113.7	86.2	0.003	0.1392	0.297	14.7664
MT-HC1-O-G2	70.1	49.5	0.004	0.2126	0.318	15.7918
MT-HC1-O-G3	83.1	59.6	0.005	0.2230	0.306	15.1833
MT-HC1-O-G4	136.4	103.5	0.003	0.1473	0.309	15.4146
MT-HC1-O-G5	89.0	67.4	0.006	0.2776	0.275	13.6323
MT-HC2-C-G1	100.6	72.4	0.015	0.7614	0.290	14.4557
MT-HC2-C-G2	74.9	53.7	0.009	0.4478	0.274	13.5719
MT-HC2-C-G3	92.0	67.6	0.017	0.8234	0.329	16.3584
MT-HC2-C-G4	76.6	58.5	0.013	0.6328	0.276	13.7005
MT-HC2-C-G5	87.7	64.9	0.017	0.8657	0.322	16.0563
MT-HC2-O-G1	81.1	59.0	0.014	0.6767	0.328	16.3156
MT-HC2-O-G2	104.8	78.2	0.010	0.5028	0.275	13.6811
MT-HC2-O-G3	72.8	54.9	0.014	0.7059	0.360	17.8490
MT-HC2-O-G4	100.9	75.2	0.011	0.5649	0.335	16.6982
MT-HC2-O-G5	117.0	88.5	0.009	0.4627	0.318	15.8245

Appendix C
pH, ORP and total Cd and Zn in soil

Table C-1: pH, ORP and total Cd and Zn in soil for pot experiment

Code	pH	ORP	Cd		df	Zn	
		mV	mg/L	mg/kg		mg/L	mg/kg
IS-C-S1	7.43	1.6	0.953	79.1003	1.282	28.141	2994.4192
IS-C-S2	7.62	81.0	0.928	76.4033	1.282	27.442	2895.5052
IS-C-S3	7.75	154.9	0.987	81.2593	1.282	29.789	3143.1686
IS-C-S4	7.38	128.9	1.063	88.4359	1.282	34.658	3696.4689
IS-C-S5	7.35	153.3	1.015	84.2603	1.282	31.448	3346.8650
IS-L1-S1	7.68	119.6	0.986	81.7714	10	4.441	3683.0320
IS-L1-S2	7.77	-182.8	0.954	78.9997	10	4.133	3422.4909
IS-L1-S3	7.60	74.7	0.996	81.9753	10	4.053	3335.8025
IS-L1-S4	7.53	-48.2	1.027	85.1011	10	3.905	3235.8303
IS-L1-S5	8.07	106.0	1.013	83.5257	10	4.061	3348.4499
IS-L2-S1	8.65	-247.6	0.968	79.6970	10	4.014	3304.7917
IS-L2-S2	8.28	209.8	1.016	84.1338	10	4.027	3334.7135
IS-L2-S3	8.41	-214.4	0.969	80.3883	10	4.109	3408.8269
IS-L2-S4	8.16	-213.6	1.081	89.0592	10	4.043	3330.8618
IS-L2-S5	8.16	-234.7	0.932	77.0375	10	3.784	3127.7897
IS-O1-1-S1	7.79	122.2	1.014	83.3882	10	3.757	3089.6382
IS-O1-1-S2	7.36	122.7	1.002	82.6324	10	4.138	3412.5021
IS-O1-1-S3	7.84	107.4	1.041	85.8486	10	4.000	3298.6970
IS-O1-1-S4	7.89	130.2	1.003	83.4443	10	3.894	3239.6007
IS-O1-1-S5	7.03	141.4	1.002	82.8510	10	4.020	3323.9623
IS-O1-2-S1	7.12	212.4	0.997	82.5741	10	3.745	3101.7061
IS-O1-2-S2	7.28	102.9	1.027	84.5128	10	3.780	3110.5991
IS-O1-2-S3	7.16	119.0	1.090	90.0529	10	3.741	3090.7138
IS-O1-2-S4	7.34	50.1	1.033	85.5699	10	3.981	3297.7137
IS-O1-2-S5	7.12	268.5	0.999	82.8496	10	3.840	3184.6077
IS-O1-3-S1	7.62	109.6	0.997	82.7798	10	3.910	3246.4298
IS-O1-3-S2	7.89	80.9	0.981	81.5326	10	3.790	3149.9335
IS-O1-3-S3	7.17	122.6	0.987	82.0040	10	3.975	3302.5922
IS-O1-3-S4	7.72	110.8	1.021	84.1576	10	3.774	3110.7814
IS-O1-3-S5	7.33	114.9	1.021	84.6881	10	3.796	3148.6397
IS-BL-S1	7.76	-185.2	0.974	80.4560	10	3.676	3036.5108
IS-BL-S2	8.26	29.4	1.050	86.7625	10	4.154	3432.4905
IS-BL-S3	8.36	126.8	1.015	83.7182	10	3.759	3100.4619
IS-BL-S4	8.24	128.8	1.079	89.1441	10	4.060	3354.2631

Code	pH	ORP	Cd		df	Zn	
		mV	mg/L	mg/kg		mg/L	mg/kg
IS-BL-S5	7.87	88.9	1.011	83.7614	10	3.979	3296.6031
IS-O2-S1	7.47	119.4	1.045	85.9941	10	3.863	3178.9006
IS-O2-S2	7.80	77.1	1.004	82.6882	10	3.856	3175.7536
IS-O2-S3	7.50	-54.7	1.030	84.8295	10	3.821	3146.9280
IS-O2-S4	7.27	104.1	1.035	85.4948	10	4.068	3360.3172
IS-O2-S5	7.82	83.2	1.028	84.7765	10	3.719	3066.9635
VG-C-S1	7.05	-147.3	1.041	86.5624	1.382	19.674	2260.8904
VG-C-S2	7.32	-15.5	1.023	85.1648	1.382	26.775	3080.5070
VG-C-S3	7.60	-78.4	0.923	76.7216	1.382	26.016	2990.1956
VG-C-S4	6.97	4.3	1.010	84.1667	1.382	27.999	3224.5515
VG-C-S5	7.48	-192.2	0.988	81.8747	1.382	27.615	3162.9314
VG-L1-S1	7.40	-256.2	1.081	89.5164	10	4.441	3677.5422
VG-L1-S2	7.29	-205.1	1.078	89.2680	10	4.133	3422.4909
VG-L1-S3	7.59	-119.1	0.981	81.5046	10	4.053	3369.0773
VG-L1-S4	7.47	-183.1	1.020	84.1168	10	3.905	3220.3530
VG-L1-S5	7.45	-71.0	1.068	88.6896	10	4.061	3372.3634
VG-L2-S1	7.61	-254.5	0.994	82.6846	10	4.014	3338.3234
VG-L2-S2	7.96	-226.6	0.993	82.2623	10	4.027	3334.7135
VG-L2-S3	7.95	-270.3	0.993	81.7718	10	4.109	3383.0068
VG-L2-S4	7.75	-244.0	1.010	83.8174	10	4.043	3355.1867
VG-L2-S5	7.89	-241.5	1.005	83.4856	10	3.784	3143.3793
VG-O1-1-S1	6.92	-135.2	0.984	80.8084	10	3.757	3086.5922
VG-O1-1-S2	7.57	-96.5	0.953	78.8232	10	4.138	3424.3628
VG-O1-1-S3	7.43	-155.3	0.985	81.0351	10	4.000	3291.0976
VG-O1-1-S4	7.48	-111.3	1.014	83.6772	10	3.894	3213.4016
VG-O1-1-S5	7.11	-158.8	1.045	86.0933	10	4.020	3311.9130
VG-O1-2-S1	7.07	-153.1	1.054	87.2517	10	3.745	3100.1656
VG-O1-2-S2	6.99	-161.0	1.009	83.8179	10	3.780	3140.0565
VG-O1-2-S3	7.66	-126.6	1.050	86.2211	10	3.741	3071.9330
VG-O1-2-S4	7.63	-50.6	1.128	93.7500	10	3.981	3308.6769
VG-O1-2-S5	6.61	-187.3	1.106	91.4050	10	3.840	3173.5537
VG-O1-3-S1	6.92	-145.7	1.031	84.8699	10	3.910	3218.6368
VG-O1-3-S2	7.31	3.6	0.939	77.8035	10	3.790	3138.9763
VG-O1-3-S3	7.50	-40.1	1.038	85.6436	10	3.975	3279.7030
VG-O1-3-S4	7.57	-157.6	1.014	83.4293	10	3.774	3105.1506
VG-O1-3-S5	7.66	-250.5	1.028	85.4815	10	3.796	3156.4943
VG-BL-S1	7.26	-234.1	1.052	87.3319	10	3.676	3051.6354
VG-BL-S2	7.35	-171.3	1.075	88.7403	10	4.154	3429.0903
VG-BL-S3	7.32	-170.7	0.991	82.3495	10	3.759	3125.2078
VG-BL-S4	7.36	-162.0	0.984	81.9704	10	4.060	3381.0793
VG-BL-S5	7.64	-125.6	1.011	83.3333	10	3.979	3279.7560
VG-O2-S1	7.32	-171.5	1.058	87.7863	10	3.863	3205.2771

Code	pH	ORP	Cd		df	Zn	
		mV	mg/L	mg/kg		mg/L	mg/kg
VG-O2-S2	6.85	-149.4	1.034	86.1667	10	3.856	3213.3333
VG-O2-S3	7.05	-191.9	1.054	87.3529	10	3.821	3166.7495
VG-O2-S4	7.10	-157.1	1.089	89.9257	10	4.068	3359.2073
VG-O2-S5	7.41	-190.2	1.048	86.6116	10	3.719	3073.5537
PF-C-S1	6.90	-171.9	0.972	80.9563	1.282	28.071	2997.9192
PF-C-S2	7.03	-145.9	0.994	82.2138	1.282	27.411	2907.0898
PF-C-S3	7.04	-208.8	0.998	82.7612	1.282	27.897	2965.5020
PF-C-S4	7.18	-181.3	1.088	89.4737	1.282	29.367	3096.0933
PF-C-S5	7.50	-154.6	1.115	92.2402	1.282	30.090	3191.2128
PF-L1-S1	7.36	-269.0	0.997	82.7054	10	3.791	3146.0581
PF-L1-S2	7.47	-258.1	1.031	84.7583	10	3.827	3146.1690
PF-L1-S3	7.52	-195.7	1.091	90.4493	10	3.947	3272.2600
PF-L1-S4	7.64	-222.5	1.017	84.3284	10	4.124	3419.5688
PF-L1-S5	7.59	-223.1	1.003	82.9063	10	3.838	3172.4252
PF-L2-S1	7.72	-290.4	0.974	80.1596	10	3.818	3141.8697
PF-L2-S2	7.78	-272.9	1.027	84.6940	10	3.990	3290.4503
PF-L2-S3	7.65	-281.7	1.011	83.8448	10	3.902	3236.0259
PF-L2-S4	7.62	-281.0	0.985	81.4806	10	3.844	3179.4872
PF-L2-S5	7.95	-269.5	1.051	86.8882	10	3.778	3123.3466
PF-O1-1-S1	7.03	-197.8	0.982	81.2945	10	3.776	3125.3104
PF-O1-1-S2	6.97	-164.7	1.049	86.9673	10	4.030	3341.0711
PF-O1-1-S3	7.11	-203.1	1.013	83.3882	10	3.909	3217.8136
PF-O1-1-S4	6.96	-225.5	1.024	85.1772	10	3.865	3214.9393
PF-O1-1-S5	7.13	-99.1	1.051	86.2748	10	3.941	3235.1010
PF-O1-2-S1	7.07	-70.9	0.972	80.4420	10	3.800	3145.1746
PF-O1-2-S2	7.00	-221.5	0.988	81.7309	10	3.807	3149.9255
PF-O1-2-S3	7.06	-176.8	1.033	85.9544	10	3.944	3281.7441
PF-O1-2-S4	6.96	-161.0	1.044	85.8553	10	3.806	3129.9342
PF-O1-2-S5	7.36	-158.5	1.115	92.6695	10	4.108	3414.2287
PF-O1-3-S1	7.34	-201.9	1.067	88.2110	10	3.941	3258.1019
PF-O1-3-S2	7.34	-232.9	1.028	85.3395	10	3.898	3235.9289
PF-O1-3-S3	7.40	-177.8	0.999	82.9376	10	3.785	3142.6436
PF-O1-3-S4	7.19	-218.4	1.007	83.4300	10	3.957	3278.3761
PF-O1-3-S5	7.32	-224.6	0.972	80.1105	10	3.810	3140.4550
PF-BL-S1	7.51	-225.5	1.062	87.2638	10	4.058	3334.4289
PF-BL-S2	7.51	-364.4	1.015	83.4155	10	3.826	3144.3130
PF-BL-S3	7.57	-212.6	1.098	90.7438	10	3.895	3219.0083
PF-BL-S4	7.73	-211.3	0.989	81.9410	10	3.945	3269.5177
PF-BL-S5	7.27	-186.7	1.085	89.5806	10	4.072	3361.9551
PF-O2-S1	7.13	-243.0	1.106	91.2391	20	2.295	3786.5039
PF-O2-S2	7.09	-139.1	1.067	88.2548	20	2.308	3818.0314
PF-O2-S3	7.49	-227.5	1.054	87.3674	20	2.273	3768.2361

Code	pH	ORP	Cd		df	Zn	
		mV	mg/L	mg/kg		mg/L	mg/kg
PF-O2-S4	7.17	-239.0	1.021	84.9276	20	2.110	3510.2312
PF-O2-S5	7.15	-165.6	1.013	83.8437	20	2.245	3716.2721
MT-C-S1	7.48	-199.6	1.090	90.4248	1.382	27.825	3190.6862
MT-C-S2	7.51	-241.8	1.009	84.0693	1.382	28.809	3317.2836
MT-C-S3	6.72	64.8	0.971	79.9292	1.382	26.337	2995.2052
MT-C-S4	7.23	-115.1	0.999	82.1035	1.382	28.083	3189.0473
MT-C-S5	7.42	-151.0	1.053	87.5457	1.382	29.259	3361.8173
MT-L1-S1	7.33	-231.2	1.011	83.8587	20	2.258	3745.8527
MT-L1-S2	7.26	-230.0	1.000	83.0040	20	2.269	3767.8512
MT-L1-S3	7.43	-202.2	1.004	82.7973	20	2.130	3513.1123
MT-L1-S4	7.22	-251.3	1.083	89.7117	20	2.155	3570.2452
MT-L1-S5	7.10	-206.5	1.104	91.3454	20	2.197	3635.6115
MT-L2-S1	7.52	-234.7	0.961	79.1529	20	2.141	3528.3454
MT-L2-S2	7.56	-302.1	1.070	87.7193	20	2.069	3392.3594
MT-L2-S3	7.80	-215.5	1.055	87.2189	20	2.218	3667.3280
MT-L2-S4	7.71	-285.1	1.077	89.3776	20	2.235	3709.5436
MT-L2-S5	7.62	-166.3	1.002	82.7826	20	2.061	3405.4858
MT-O1-1-S1	6,7	183.7	1.062	88.0597	20	2.034	3373.1343
MT-O1-1-S2	6.89	-28.3	1.087	89.6717	20	2.300	3794.7533
MT-O1-1-S3	6.75	-196.3	1.014	83.8155	20	2.204	3643.5775
MT-O1-1-S4	6.45	208.4	1.049	87.2422	20	2.210	3675.9814
MT-O1-1-S5	6.68	-153.8	1.094	90.8185	20	2.169	3601.1954
MT-O1-2-S1	6.93	-185.9	1.061	87.8893	20	2.015	3338.3035
MT-O1-2-S2	6.76	-85.8	1.162	96.6401	20	2.170	3609.4478
MT-O1-2-S3	6.79	-183.2	1.061	87.1100	20	2.097	3443.3498
MT-O1-2-S4	6.63	201.4	1.004	83.3278	20	2.326	3860.5809
MT-O1-2-S5	6.75	-206.1	1.041	86.5768	20	2.051	3411.5103
MT-O1-3-S1	7.27	203.3	1.120	93.0851	20	2.264	3763.2979
MT-O1-3-S2	6.09	-180.8	1.055	87.6683	20	2.125	3531.6603
MT-O1-3-S3	7.30	-225.0	1.104	90.6404	20	2.118	3477.8325
MT-O1-3-S4	7.39	-256.4	1.063	87.8512	20	2.086	3447.9339
MT-O1-3-S5	7.28	-135.0	0.992	82.5458	20	2.037	3389.3511
MT-BL-S1	7.50	-215.0	1.060	88.2598	20	2.203	3668.6095
MT-BL-S2	7.41	-249.9	0.982	81.2800	20	2.195	3634.7077
MT-BL-S3	7.53	-245.1	0.995	82.6578	20	2.362	3923.5880
MT-BL-S4	7.26	-218.9	1.148	95.5870	20	2.254	3753.5387
MT-BL-S5	7.10	-150.2	1.077	89.1409	20	2.256	3734.4810
MT-O2-S1	7.52	19.0	1.067	88.6654	20	2.094	3480.1396
MT-O2-S2	7.49	-114.7	1.036	85.7048	20	2.171	3591.9921
MT-O2-S3	7.30	-247.5	1.004	83.2919	20	2.007	3330.0149
MT-O2-S4	7.45	-227.2	1.067	88.6507	20	1.910	3173.8119
MT-O2-S5	7.20	-129.9	1.028	85.4388	20	2.054	3414.2287

Table C-2: pH, ORP and total Cd and Zn in soil for field experiment

Code	pH	ORP	Cd		Zn	
		(mV)	mg/L	mg/kg	mg/L	mg/kg
BG-LC1-C-S1	6.65	9.2	0.003	0.2461	1.696	139.1304
BG-LC1-C-S2	6.03	-184.8	0.003	0.2485	1.537	127.3194
BG-LC1-C-S3	6.28	467.3	0.004	0.3327	1.265	105.2063
BG-LC1-C-S4	6.33	135.6	0.004	0.3330	1.140	94.9051
BG-LC1-C-S5	6.17	11.7	0.003	0.2487	1.035	85.8067
BG-LC1-O-S1	6.41	-103.0	0.002	0.1652	0.869	71.7176
BG-LC1-O-S2	6.67	73.0	0.005	0.4118	1.481	121.9733
BG-LC1-O-S3	6.44	-2.1	0.002	0.1659	0.850	70.5028
BG-LC1-O-S4	6.52	-103.7	0.008	0.6640	1.609	133.5491
BG-LC1-O-S5	6.70	-165.0	0.005	0.4151	1.447	120.1229
BG-LC2-C-S1	7.06	-8.2	0.006	0.4946	3.331	274.5631
BG-LC2-C-S2	7.50	-91.5	0.006	0.4944	4.306	354.8121
BG-LC2-C-S3	7.61	-8.2	0.004	0.3316	1.427	118.2858
BG-LC2-C-S4	6.30	2.9	0.004	0.3313	1.109	91.8655
BG-LC2-C-S5	6.14	29.6	0.008	0.6570	0.657	53.9586
BG-LC2-O-S1	6.16	76.9	0.106	8.7865	0.888	73.6240
BG-LC2-O-S2	6.34	99.9	0.096	7.9840	0.925	76.9128
BG-LC2-O-S3	6.90	-101.9	0.111	9.1979	0.862	71.4203
BG-LC2-O-S4	6.63	-26.2	0.048	3.9578	0.765	63.0607
BG-LC2-O-S5	6.25	200.9	0.091	7.4664	0.910	74.6882
BG-HC1-C-S1	7.46	-36.6	0.231	19.1988	3.720	309.1755
BG-HC1-C-S2	7.56	-116.9	0.234	19.3869	5.470	453.1897
BG-HC1-C-S3	7.58	-140.5	0.127	10.4269	3.620	297.2085
BG-HC1-C-S4	7.56	9.5	0.255	21.1233	3.370	279.1584
BG-HC1-C-S5	7.36	42.3	0.099	8.2103	3.420	283.6291
BG-HC1-O-S1	7.49	-45.5	0.040	3.3132	2.410	199.8673
BG-HC1-O-S2	7.12	25.5	0.053	4.4042	3.070	255.1105
BG-HC1-O-S3	7.65	39.5	0.029	2.3732	2.120	175.7294
BG-HC1-O-S4	7.62	-2.3	0.028	2.3239	2.340	193.0375
BG-HC1-O-S5	7.60	-140.1	0.033	2.7432	2.390	198.0772
BG-HC2-C-S1	7.70	-5.6	0.898	74.6151	39.750	3302.0435
BG-HC2-C-S2	7.65	-29.3	0.870	72.2155	34.980	2904.8331
BG-HC2-C-S3	7.66	-9.4	0.990	82.1745	40.070	3327.5203
BG-HC2-C-S4	7.50	-144.7	0.881	72.9435	43.590	3607.8464
BG-HC2-C-S5	7.70	-83.3	0.883	72.5572	40.440	3321.2878
BG-HC2-O-S1	7.52	-79.0	0.236	19.6601	7.020	584.8051
BG-HC2-O-S2	7.56	-148.7	0.310	25.4641	7.620	625.9241
BG-HC2-O-S3	7.93	-100.3	0.212	17.5963	6.940	576.0292
BG-HC2-O-S4	7.58	-2.9	0.152	12.5268	6.480	534.0366
BG-HC2-O-S5	7.36	-109.2	0.250	20.5660	7.050	579.9605
OA-LC1-C-S1	6.60	-118.9	0.004	0.3322	1.668	138.5284
OA-LC1-C-S2	6.76	-235.1	0.003	0.2479	1.308	108.0337
OA-LC1-C-S3	6.43	-216.4	0.004	0.3298	1.427	117.6506
OA-LC1-C-S4	6.63	-164.7	0.003	0.2486	1.304	108.0373
OA-LC1-C-S5	6.66	-242.2	0.004	0.3326	1.372	114.0645
OA-LC1-O-S1	6.87	-149.4	0.003	0.2461	1.128	92.5349
OA-LC1-O-S2	6.81	468.6	0.005	0.4157	1.407	116.9771

Code	pH	ORP	Cd		Zn	
		(mV)	mg/L	mg/kg	mg/L	mg/kg
OA-LC1-O-S3	6.74	-242.3	0.005	0.4130	1.354	111.8454
OA-LC1-O-S4	6.47	-105.2	0.006	0.4995	1.248	103.8961
OA-LC1-O-S5	6.44	-194.8	0.009	0.7427	2.186	180.3928
OA-LC2-C-S1	6.83	-200.0	0.020	1.6586	4.044	335.3790
OA-LC2-C-S2	7.35	-178.2	0.024	1.9851	4.084	337.7998
OA-LC2-C-S3	6.78	-75.3	0.020	1.6499	1.910	157.5648
OA-LC2-C-S4	6.38	-176.6	0.008	0.6636	1.034	85.7664
OA-LC2-C-S5	6.71	-172.0	0.006	0.4971	0.900	74.5899
OA-LC2-O-S1	6.12	-131.6	0.006	0.4974	0.912	75.6342
OA-LC2-O-S2	6.48	-118.6	0.003	0.2486	0.825	68.3905
OA-LC2-O-S3	6.33	-198.8	0.005	0.4151	0.873	72.4722
OA-LC2-O-S4	6.33	-89.4	0.004	0.3292	0.893	73.4612
OA-LC2-O-S5	6.23	-68.0	0.003	0.2496	0.767	63.8209
OA-HC1-C-S1	8.26	-128.7	0.186	15.3923	5.130	424.5283
OA-HC1-C-S2	7.32	-218.6	0.154	12.7780	4.750	394.1255
OA-HC1-C-S3	6.76	-159.1	0.107	8.8915	4.420	367.2927
OA-HC1-C-S4	7.30	-183.6	0.100	8.2699	3.800	314.2574
OA-HC1-C-S5	7.25	-145.7	0.126	10.3789	3.260	268.5338
OA-HC1-O-S1	7.27	-200.0	0.074	6.1076	4.370	360.6801
OA-HC1-O-S2	7.48	-99.8	0.026	2.1616	2.360	196.2088
OA-HC1-O-S3	7.41	-52.7	0.030	2.4888	2.410	199.9336
OA-HC1-O-S4	7.35	-133.3	0.163	13.5517	2.510	208.6797
OA-HC1-O-S5	7.24	-24.9	0.128	10.5663	2.290	189.0375
OA-HC2-C-S1	7.33	-163.3	0.854	70.0539	41.165	3377.5041
OA-HC2-C-S2	7.22	-195.4	0.680	56.4326	30.422	2526.3129
OA-HC2-C-S3	7.10	-132.2	0.917	75.7944	42.844	3542.0337
OA-HC2-C-S4	7.23	-116.9	0.682	56.6222	33.332	2767.5191
OA-HC2-C-S5	7.24	-172.0	0.917	75.7318	49.101	4055.8896
OA-HC2-O-S1	7.29	-187.5	0.234	19.3682	7.340	607.0129
OA-HC2-O-S2	7.01	-49.2	0.206	17.0851	6.950	577.8184
OA-HC2-O-S3	7.43	-217.8	0.209	17.2220	7.160	590.5642
OA-HC2-O-S4	7.23	-78.9	0.207	17.1504	7.090	587.9914
OA-HC2-O-S5	7.43	-165.4	0.245	20.2913	7.430	614.8626
VG-LC1-C-S1	6.59	-64.6	0.003	0.2495	1.378	114.5975
VG-LC1-C-S2	6.34	-75.3	0.002	0.1659	1.194	99.0588
VG-LC1-C-S3	6.51	-197.3	0.002	0.1665	1.286	107.0468
VG-LC1-C-S4	6.57	-211.3	0.002	0.1650	1.349	111.2575
VG-LC1-C-S5	6.64	-184.6	0.003	0.2495	1.340	111.4180
VG-LC1-O-S1	6.48	-172.4	0.003	0.2116	1.382	113.7636
VG-LC1-O-S2	6.61	-178.6	0.002	0.1927	1.277	106.1513
VG-LC1-O-S3	6.50	-237.3	-	-	-	-
VG-LC1-O-S4	6.72	-198.1	0.003	0.2258	1.305	107.9940
VG-LC1-O-S5	6.64	-206.9	0.004	0.3127	1.968	162.0553
VG-LC2-C-S1	6.75	-261.0	0.016	1.3263	2.666	220.9715
VG-LC2-C-S2	6.67	-224.0	0.018	1.4810	6.576	541.0564
VG-LC2-C-S3	6.76	-220.7	0.010	0.8281	1.240	102.6996
VG-LC2-C-S4	6.69	-205.5	0.006	0.4980	0.913	75.7719
VG-LC2-C-S5	6.71	-194.7	0.005	0.4121	0.805	66.3452
VG-LC2-O-S1	6.66	-213.0	0.004	0.3290	0.752	61.8112
VG-LC2-O-S2	6.72	-203.4	0.003	0.2496	0.729	60.6240

Code	pH	ORP	Cd		Zn	
		(mV)	mg/L	mg/kg	mg/L	mg/kg
VG-LC2-O-S3	6.70	-225.8	0.003	0.2465	0.711	58.4470
VG-LC2-O-S4	6.71	-187.4	0.003	0.2474	0.712	58.7595
VG-LC2-O-S5	6.67	-204.0	0.002	0.1664	0.690	57.4472
VG-HC1-C-S1	7.04	-189.2	0.095	7.8864	4.910	407.6042
VG-HC1-C-S2	6.97	-127.0	0.133	11.0337	4.610	382.4457
VG-HC1-C-S3	6.96	-25.1	0.125	10.3580	3.930	325.6546
VG-HC1-C-S4	6.95	-77.2	0.055	4.5372	3.750	309.3549
VG-HC1-C-S5	6.91	-31.3	0.056	4.6022	3.680	302.4326
VG-HC1-O-S1	6.99	-115.6	0.098	8.0831	3.110	256.5160
VG-HC1-O-S2	6.85	46.2	0.067	5.5491	2.470	204.5718
VG-HC1-O-S3	7.01	58.1	0.052	4.2904	2.310	190.5941
VG-HC1-O-S4	6.93	-59.2	0.070	5.7642	2.600	214.0975
VG-HC1-O-S5	7.11	-140.5	0.089	7.3059	2.810	230.6682
VG-HC2-C-S1	7.02	26.6	0.853	70.6711	38.870	3220.3811
VG-HC2-C-S2	7.05	-121.0	0.803	66.0576	33.980	2796.7078
VG-HC2-C-S3	6.96	-62.5	0.777	64.4610	33.710	2795.1907
VG-HC2-C-S4	7.00	48.0	0.794	65.9684	38.700	3216.9576
VG-HC2-C-S5	6.88	2.9	0.935	76.8706	37.990	3123.6639
VG-HC2-O-S1	6.90	-160.3	0.248	20.4048	7.290	599.8025
VG-HC2-O-S2	6.92	-187.8	0.184	15.0968	7.520	617.0003
VG-HC2-O-S3	6.85	-121.7	0.197	16.4003	6.790	565.2681
VG-HC2-O-S4	6.94	-118.0	0.179	14.8081	7.110	588.1866
VG-HC2-O-S5	7.01	-152.4	0.192	15.9151	7.160	593.5013
PF-LC1-C-S1	6.30	-7.8	0.001	0.1146	1.899	155.7579
PF-LC1-C-S2	6.40	-240.4	0.002	0.1345	1.628	134.6345
PF-LC1-C-S3	5.62	-133.5	0.001	0.1211	1.493	123.8182
PF-LC1-C-S4	6.30	-36.3	0.002	0.1337	1.513	124.3630
PF-LC1-C-S5	6.38	-172.8	0.002	0.1561	1.513	125.4145
PF-LC1-O-S1	6.66	-51.2	0.330	26.8555	1.355	110.2702
PF-LC1-O-S2	6.65	-238.2	0.279	22.8436	1.488	122.0072
PF-LC1-O-S3	6.25	-54.4	0.316	25.7047	1.492	121.5578
PF-LC1-O-S4	6.42	-204.1	0.156	12.8531	1.467	121.1796
PF-LC1-O-S5	6.65	-262.8	0.125	10.2587	2.289	188.6124
PF-LC2-C-S1	6.84	-207.8	0.037	3.0850	1.930	160.4856
PF-LC2-C-S2	6.39	-228.4	0.038	3.1297	1.998	165.4247
PF-LC2-C-S3	6.33	-198.6	0.032	2.6625	1.251	103.9555
PF-LC2-C-S4	6.53	-250.4	0.031	2.5635	1.321	109.7358
PF-LC2-C-S5	6.65	-247.0	0.028	2.2793	1.221	100.9091
PF-LC2-O-S1	6.52	-250.1	0.020	1.6583	1.016	84.5821
PF-LC2-O-S2	6.53	-262.3	0.017	1.4366	0.992	81.8940
PF-LC2-O-S3	5.75	-62.0	0.018	1.4793	0.991	81.5452
PF-LC2-O-S4	6.13	-193.9	0.015	1.2836	1.042	86.3441
PF-LC2-O-S5	6.05	-181.3	0.013	1.1087	0.898	74.5062
PF-HC1-C-S1	7.08	-282.8	0.379	31.1985	5.985	493.3234
PF-HC1-C-S2	7.00	-157.3	0.378	31.3724	6.135	509.0441
PF-HC1-C-S3	7.01	-191.8	0.432	35.9375	4.278	355.5519
PF-HC1-C-S4	6.94	-241.4	0.403	33.3031	4.662	384.9711
PF-HC1-C-S5	7.00	-216.4	0.260	21.3487	3.594	295.5592
PF-HC1-O-S1	7.03	-215.1	0.106	8.7451	3.135	258.1522
PF-HC1-O-S2	7.08	-96.6	0.228	18.7397	2.645	217.5469

Code	pH	ORP	Cd		Zn	
		(mV)	mg/L	mg/kg	mg/L	mg/kg
PF-HC1-O-S3	7.24	-129.4	0.402	33.4833	2.697	224.7750
PF-HC1-O-S4	7.07	-220.4	0.500	41.6015	3.024	251.4552
PF-HC1-O-S5	7.19	-198.3	0.440	36.1216	2.738	224.9795
PF-HC2-C-S1	7.21	-25.9	-	-	-	-
PF-HC2-C-S2	7.11	-254.7	0.761	62.4569	37.124	3046.4677
PF-HC2-C-S3	7.03	-61.7	0.664	55.0880	34.007	2822.6529
PF-HC2-C-S4	7.20	-39.0	0.917	75.6601	42.365	3495.4822
PF-HC2-C-S5	7.26	-135.4	0.810	67.4300	33.400	2781.4602
PF-HC2-O-S1	7.05	-116.7	0.522	43.0386	15.385	1268.9706
PF-HC2-O-S2	7.17	-59.7	0.505	41.4532	16.800	1379.3103
PF-HC2-O-S3	7.12	-187.9	0.458	37.8825	12.180	1007.4442
PF-HC2-O-S4	7.04	-202.5	1.055	85.4528	10.920	884.4970
PF-HC2-O-S5	7.12	-263.4	-	-	-	-
MT-LC1-C-S1	5.81	228.9	0.002	0.1605	1.282	105.3756
MT-LC1-C-S2	6.44	196.0	0.001	0.0905	1.133	93.8535
MT-LC1-C-S3	6.57	217.3	0.001	0.0413	1.132	93.1381
MT-LC1-C-S4	5.89	187.5	0.000	0.0393	1.208	100.1658
MT-LC1-C-S5	5.78	498.9	0.001	0.0525	1.317	109.4945
MT-LC1-O-S1	6.00	178.2	0.001	0.0458	0.946	78.5465
MT-LC1-O-S2	6.37	84.0	0.000	0.0385	0.987	81.7534
MT-LC1-O-S3	6.59	119.8	0.001	0.0424	1.043	86.7576
MT-LC1-O-S4	6.45	204.2	0.001	0.0600	1.032	84.8126
MT-LC1-O-S5	6.02	3.4	0.001	0.1163	1.273	105.7309
MT-LC2-C-S1	5.99	0.1	0.039	3.2351	3.775	312.3449
MT-LC2-C-S2	6.02	150.8	0.040	3.2952	5.390	446.2659
MT-LC2-C-S3	5.19	242.8	0.037	3.0728	2.255	187.0748
MT-LC2-C-S4	5.93	179.4	0.038	3.1393	1.867	154.8093
MT-LC2-C-S5	5.21	103.0	0.030	2.4617	1.579	131.4081
MT-LC2-O-S1	4.89	254.1	0.029	2.3997	1.175	96.5648
MT-LC2-O-S2	5.74	138.1	0.017	1.4267	1.071	87.8157
MT-LC2-O-S3	5.30	332.8	0.020	1.6625	1.069	88.9499
MT-LC2-O-S4	5.40	241.2	0.016	1.3662	1.129	93.5377
MT-LC2-O-S5	5.39	245.0	0.018	1.5254	0.994	82.5939
MT-HC1-C-S1	7.46	158.7	0.073	5.9881	6.395	527.9016
MT-HC1-C-S2	7.49	187.5	0.061	5.0223	5.770	477.0961
MT-HC1-C-S3	7.67	223.5	0.057	4.7236	5.555	462.4542
MT-HC1-C-S4	7.47	116.6	0.053	4.4188	5.558	462.7810
MT-HC1-C-S5	7.42	214.0	0.041	3.3493	4.390	361.6145
MT-HC1-O-S1	7.47	122.0	0.016	1.3247	3.484	286.8434
MT-HC1-O-S2	7.50	236.8	0.004	0.3652	2.793	229.7253
MT-HC1-O-S3	7.57	155.1	0.005	0.4331	2.836	233.9548
MT-HC1-O-S4	7.52	180.4	0.002	0.1653	2.613	215.9147
MT-HC1-O-S5	7.39	115.0	0.012	0.9931	3.343	276.4181
MT-HC2-C-S1	7.23	110.3	0.913	75.5712	38.379	3177.0889
MT-HC2-C-S2	7.50	160.1	0.743	61.0053	29.353	2410.6991
MT-HC2-C-S3	7.39	175.3	0.861	70.9672	33.876	2790.8690
MT-HC2-C-S4	7.54	220.3	0.853	71.0561	35.668	2970.8316
MT-HC2-C-S5	7.55	212.1	0.918	76.0189	38.145	3159.7604
MT-HC2-O-S1	6.90	147.8	0.192	15.9076	6.834	565.9159
MT-HC2-O-S2	6.79	77.2	0.186	15.4716	6.795	565.2138

Code	pH	ORP	Cd		Zn	
		(mV)	mg/L	mg/kg	mg/L	mg/kg
MT-HC2-O-S3	6.78	114.1	0.157	13.0056	6.153	510.0298
MT-HC2-O-S4	7.20	30.3	0.115	9.4510	4.950	406.8047
MT-HC2-O-S5	6.94	462.3	0.141	11.7260	5.463	454.6438

Appendix D
Soil organic matter

Table D-1: SOM for pot experiment

Code	Weigh	V FAS Sample			FAS	$K_2Cr_2O_7$	OC	OM
	g	Intitail	Final	Tot	N	N	%	%
IS-C-1	0.5029	13.7	28.1	14.4	0.5	1.0	3.3	5.63
IS-C-2	0.5023	0.0	15	15.0	0.5	1.0	3.1	5.29
IS-C-3	0.5026	13.6	28.5	14.9	0.5	1.0	3.1	5.35
IS-O1-1-1	0.5020	0.0	14.7	14.7	0.5	1.0	3.2	5.47
IS-O1-1-2	0.5063	0.0	14.1	14.1	0.5	1.0	3.4	5.76
IS-O1-1-3	0.5038	15.2	30	14.8	0.5	1.0	3.1	5.39
IS-O1-2-1	0.5086	14.2	28.3	14.1	0.5	1.0	3.3	5.74
IS-O1-2-2	0.5008	14.0	28.5	14.5	0.5	1.0	3.3	5.60
IS-O1-2-3	0.5019	0.0	14.7	14.7	0.5	1.0	3.2	5.47
IS-O1-3-1	0.5008	0.0	14.2	14.2	0.5	1.0	3.4	5.77
IS-O1-3-2	0.5087	14.2	28	13.8	0.5	1.0	3.4	5.91
IS-O1-3-3	0.5060	30.0	44.5	14.5	0.5	1.0	3.2	5.54
IS-O1L-1	0.5089	28.6	43.9	15.3	0.5	1.0	2.9	5.05
IS-O1L-2	0.5052	29.4	43.9	14.5	0.5	1.0	3.2	5.55
IS-O1L-3	0.5098	0.0	14.8	14.8	0.5	1.0	3.1	5.33
IS-O2-1	0.5092	26.8	41.7	14.9	0.5	1.0	3.1	5.28
IS-O2-2	0.5054	0.0	14.7	14.7	0.5	1.0	3.2	5.43
IS-O2-3	0.5067	0.0	14.2	14.2	0.5	1.0	3.3	5.70
VG-C-1	0.5057	12.5	27.7	15.2	0.5	1.0	3.0	5.14
VG-C-2	0.5087	12.9	27.7	14.8	0.5	1.0	3.1	5.34
VG-C-3	0.5026	0.0	14.6	14.6	0.5	1.0	3.2	5.52
VG-O1-1-1	0.5053	13.6	28.4	14.8	0.5	1.0	3.1	5.38
VG-O1-1-2	0.5012	0.0	14.9	14.9	0.5	1.0	3.1	5.36
VG-O1-1-3	0.5032	24.7	39.8	15.1	0.5	1.0	3.0	5.23
VG-O1-2-1	0.5070	19.8	35	15.2	0.5	1.0	3.0	5.13
VG-O1-2-2	0.5047	26.1	41.3	15.2	0.5	1.0	3.0	5.15
VG-O1-2-3	0.5068	0.0	15.1	15.1	0.5	1.0	3.0	5.19
VG-O1-3-1	0.5013	24.7	39.1	14.4	0.5	1.0	3.3	5.65
VG-O1-3-2	0.5057	7.6	22.2	14.6	0.5	1.0	3.2	5.49
VG-O1-3-3	0.5039	13.2	28.2	15.0	0.5	1.0	3.1	5.28
VG-O1L-1	0.5025	25.5	40.8	15.3	0.5	1.0	3.0	5.12
VG-O1L-2	0.5095	0.0	15.2	15.2	0.5	1.0	3.0	5.10
VG-O1L-3	0.5077	0.0	15.2	15.2	0.5	1.0	3.0	5.12
VG-O2-1	0.5013	0.0	14.5	14.5	0.5	1.0	3.3	5.59
VG-O2-2	0.5020	13.1	27.8	14.7	0.5	1.0	3.2	5.47
VG-O2-3	0.5025	27.0	41.5	14.5	0.5	1.0	3.2	5.58
PF-C-1	0.5042	28.5	43.2	14.7	0.5	1.0	3.2	5.44
PF-C-2	0.5036	0.0	14.5	14.5	0.5	1.0	3.2	5.57
PF-C-3	0.5045	14.5	28.6	14.1	0.5	1.0	3.4	5.78
PF-O1-1-1	0.5055	0.0	15	15.0	0.5	1.0	3.1	5.26

Code	Weigh	V FAS Sample			FAS	$K_2Cr_2O_7$	OC	OM
	g	Intitail	Final	Tot	N	N	%	%
PF-O1-1-2	0.5034	15.0	30.2	15.2	0.5	1.0	3.0	5.17
PF-O1-1-3	0.5082	30.2	45.4	15.2	0.5	1.0	3.0	5.12
PF-O1-2-1	0.5026	0.0	14.5	14.5	0.5	1.0	3.2	5.58
PF-O1-2-2	0.5015	28.4	43.4	15.0	0.5	1.0	3.1	5.30
PF-O1-2-3	0.5025	28.6	43.4	14.8	0.5	1.0	3.1	5.41
PF-O1-3-1	0.5064	14.5	28.5	14.0	0.5	1.0	3.4	5.82
PF-O1-3-2	0.5011	0.0	13.7	13.7	0.5	1.0	3.5	6.05
PF-O1-3-3	0.5055	11.8	25.7	13.9	0.5	1.0	3.4	5.89
PF-O1L-1	0.5067	0.0	14.4	14.4	0.5	1.0	3.2	5.59
PF-O1L-2	0.5099	14.4	27.3	12.9	0.5	1.0	3.7	6.40
PF-O1L-3	0.5093	0.0	14.8	14.8	0.5	1.0	3.1	5.33
PF-O2-1	0.5046	13.7	28.4	14.7	0.5	1.0	3.2	5.44
PF-O2-2	0.5083	27.3	41.8	14.5	0.5	1.0	3.2	5.51
PF-O2-3	0.5035	27.1	41.2	14.1	0.5	1.0	3.4	5.80
MT-C-1	0.5014	0.0	15.5	15.5	0.5	1.0	2.9	5.01
MT-C-2	0.5055	15.5	30.6	15.1	0.5	1.0	3.0	5.20
MT-C-3	0.5019	30.6	45.1	14.5	0.5	1.0	3.2	5.58
MT-O1-1-1	0.5028	13.9	29	15.1	0.5	1.0	3.0	5.23
MT-O1-1-2	0.5018	29.0	44.8	15.8	0.5	1.0	2.8	4.84
MT-O1-1-3	0.5049	0.0	15.1	15.1	0.5	1.0	3.0	5.21
MT-O1-2-1	0.5066	14.8	29.8	15.0	0.5	1.0	3.1	5.25
MT-O1-2-2	0.5025	14.1	30.6	16.5	0.5	1.0	2.6	4.43
MT-O1-2-3	0.5046	30.6	44.9	14.3	0.5	1.0	3.3	5.67
MT-O1-3-1	0.5028	14.8	30.7	15.9	0.5	1.0	2.8	4.77
MT-O1-3-2	0.5034	0.0	14.8	14.8	0.5	1.0	3.1	5.40
MT-O1-3-3	0.5030	17.2	30.7	13.5	0.5	1.0	3.6	6.15
MT-O1L-1	0.5023	0.0	15.2	15.2	0.5	1.0	3.0	5.18
MT-O1L-2	0.5026	30.7	45.7	15.0	0.5	1.0	3.1	5.29
MT-O1L-3	0.5009	0.0	15.2	15.2	0.5	1.0	3.0	5.19
MT-O2-1	0.5031	0.0	13.9	13.9	0.5	1.0	3.4	5.92
MT-O2-2	0.5023	29.8	44.9	15.1	0.5	1.0	3.0	5.23
MT-O2-3	0.5031	30.7	46.6	15.9	0.5	1.0	2.8	4.77

Table D-2: SOM for field experiment

Code	Weight	V FAS Sample			FAS	$K_2Cr_2O_7$	OC	OM
	g	Intitail	Final	Total	N	N	%	%
BG-LC1-C-S1	0.5087	31.5	49.2	17.7	0.5	1.0	2.15	3.70
BG-LC1-C-S2	0.5001	0.0	18.1	18.1	0.5	1.0	2.05	3.53
BG-LC1-C-S3	0.5029	18.8	36.6	17.8	0.5	1.0	2.14	3.69
BG-LC1-C-S4	0.5005	0.0	16.7	16.7	0.5	1.0	2.52	4.34
BG-LC1-C-S5	0.5040	15.7	32.9	17.2	0.5	1.0	2.33	4.02
BG-LC1-O-S1	0.5075	0.0	17.0	17.0	0.5	1.0	2.38	4.11
BG-LC1-O-S2	0.5060	17.0	33.8	16.8	0.5	1.0	2.46	4.24
BG-LC1-O-S3	0.5040	0.0	17.1	17.1	0.5	1.0	2.37	4.08
BG-LC1-O-S4	0.5014	32.8	50.0	17.2	0.5	1.0	2.35	4.04
BG-LC1-O-S5	0.5038	15.9	31.9	16.0	0.5	1.0	2.73	4.71
BG-LC2-C-S1	0.5020	28.8	43.3	14.5	0.5	1.0	3.25	5.60
BG-LC2-C-S2	0.5009	13.6	31.6	18.0	0.5	1.0	2.08	3.58
BG-LC2-C-S3	0.5006	28.2	44.5	16.3	0.5	1.0	2.65	4.57
BG-LC2-C-S4	0.5078	14.9	30.8	15.9	0.5	1.0	2.75	4.73
BG-LC2-C-S5	0.5066	14.7	29.7	15.0	0.5	1.0	3.05	5.26
BG-LC2-O-S1	0.5048	1.0	16.5	15.5	0.5	1.0	3.06	5.28
BG-LC2-O-S2	0.5016	15.2	30.9	15.7	0.5	1.0	3.38	5.83
BG-LC2-O-S3	0.5021	0.0	16.0	16.0	0.5	1.0	3.28	5.65
BG-LC2-O-S4	0.5008	0.0	15.8	15.8	0.5	1.0	3.35	5.78
BG-LC2-O-S5	0.5045	0.0	15.8	15.8	0.5	1.0	3.33	5.74
BG-HC1-C-S1	0.5097	0.0	16.4	16.4	0.5	1.0	2.74	4.72
BG-HC1-C-S2	0.5005	15.0	31.8	16.8	0.5	1.0	3.02	5.21
BG-HC1-C-S3	0.5016	29.5	44.5	15.0	0.5	1.0	3.25	5.60
BG-HC1-C-S4	0.5003	29.5	46.1	16.6	0.5	1.0	2.72	4.69
BG-HC1-C-S5	0.5091	0.4	16.0	15.6	0.5	1.0	3.00	5.18
BG-HC1-O-S1	0.5037	20.0	38.0	18.0	0.5	1.0	2.23	3.85
BG-HC1-O-S2	0.5030	1.0	19.5	18.5	0.5	1.0	2.07	3.57
BG-HC1-O-S3	0.5065	15.8	32.9	17.1	0.5	1.0	2.52	4.35
BG-HC1-O-S4	0.5050	18.1	35.8	17.7	0.5	1.0	2.69	4.65
BG-HC1-O-S5	0.5079	1.0	19.1	18.1	0.5	1.0	2.55	4.39
BG-HC2-C-S1	0.5015	0.0	14.9	14.9	0.5	1.0	3.12	5.37
BG-HC2-C-S2	0.5014	20.6	35.0	14.4	0.5	1.0	3.28	5.66
BG-HC2-C-S3	0.5035	29.7	46.4	16.7	0.5	1.0	2.50	4.31
BG-HC2-C-S4	0.5002	0.1	15.2	15.1	0.5	1.0	3.06	5.27
BG-HC2-C-S5	0.5012	0.0	15.5	15.5	0.5	1.0	2.92	5.03
BG-HC2-O-S1	0.5010	15.3	31.1	15.8	0.5	1.0	2.98	5.15
BG-HC2-O-S2	0.5047	30.1	45.8	15.7	0.5	1.0	3.00	5.16
BG-HC2-O-S3	0.5000	0.0	14.7	14.7	0.5	1.0	3.36	5.79
BG-HC2-O-S4	0.5003	16.1	31.7	15.6	0.5	1.0	3.43	5.90
BG-HC2-O-S5	0.5500	-	-	-	-	-	-	-
OA-LC1-C-S1	0.5050	16.6	31.0	14.4	0.5	1.0	3.33	5.74
OA-LC1-C-S2	0.5016	32.2	51.0	18.8	0.5	1.0	1.88	3.23
OA-LC1-C-S3	0.5056	0.0	16.6	16.6	0.5	1.0	2.59	4.47
OA-LC1-C-S4	0.5012	16.4	34.0	17.6	0.5	1.0	2.28	3.93
OA-LC1-C-S5	0.5071	33.0	51.0	18.0	0.5	1.0	2.12	3.66
OA-LC1-O-S1	0.5065	0.2	17.2	17.0	0.5	1.0	2.45	4.23
OA-LC1-O-S2	0.5055	16.4	32.5	16.1	0.5	1.0	2.76	4.76
OA-LC1-O-S3	0.5008	31.5	48.1	16.6	0.5	1.0	2.62	4.51
OA-LC1-O-S4	0.5056	0.0	16.0	16.0	0.5	1.0	2.79	4.81
OA-LC1-O-S5	0.5005	15.7	32.7	17.0	0.5	1.0	2.48	4.28
OA-LC2-C-S1	0.5003	-1.0	12.5	13.5	0.5	1.0	3.66	6.31
OA-LC2-C-S2	0.5013	11.6	26.4	14.8	0.5	1.0	3.22	5.55
OA-LC2-C-S3	0.5030	25.4	41.7	16.3	0.5	1.0	2.71	4.66
OA-LC2-C-S4	0.5049	0.0	15.8	15.8	0.5	1.0	2.86	4.93
OA-LC2-C-S5	0.5080	14.8	30.8	16.0	0.5	1.0	2.78	4.79
OA-LC2-O-S1	0.5052	29.2	44.0	14.8	0.5	1.0	3.19	5.50
OA-LC2-O-S2	0.5107	0.0	17.1	17.1	0.5	1.0	2.40	4.14
OA-LC2-O-S3	0.5045	9.4	24.8	15.4	0.5	1.0	3.00	5.17

Code	Weight	V FAS Sample			FAS	$K_2Cr_2O_7$	OC	OM
	g	Intitail	Final	Total	N	N	%	%
OA-LC2-O-S4	0.5023	23.8	39.2	15.4	0.5	1.0	3.01	5.19
OA-LC2-O-S5	0.5018	26.6	42.3	15.7	0.5	1.0	2.91	5.02
OA-HC1-C-S1	0.5060	0.0	16.1	16.1	0.5	1.0	2.76	4.75
OA-HC1-C-S2	0.5073	15.7	31.7	16.0	0.5	1.0	2.78	4.80
OA-HC1-C-S3	0.5038	30.7	47.1	16.4	0.5	1.0	2.67	4.60
OA-HC1-C-S4	0.5088	0.0	15.9	15.9	0.5	1.0	2.81	4.84
OA-HC1-C-S5	0.5059	14.9	31.7	16.8	0.5	1.0	2.52	4.35
OA-HC1-O-S1	0.5048	30.7	46.7	16.0	0.5	1.0	2.80	4.82
OA-HC1-O-S2	0.5046	0.0	18.4	18.4	0.5	1.0	2.00	3.44
OA-HC1-O-S3	0.5073	13.4	31.9	18.5	0.5	1.0	1.95	3.37
OA-HC1-O-S4	0.5075	33.1	49.9	16.8	0.5	1.0	2.52	4.34
OA-HC1-O-S5	0.5024	0.0	17.6	17.6	0.5	1.0	2.27	3.92
OA-HC2-C-S1	0.5040	31.5	46.8	15.3	0.5	1.0	3.03	5.23
OA-HC2-C-S2	0.5044	0.0	12.5	12.5	0.5	1.0	3.96	6.83
OA-HC2-C-S3	0.5027	11.0	23.3	12.3	0.5	1.0	4.04	6.97
OA-HC2-C-S4	0.5035	22.3	35.8	13.5	0.5	1.0	3.64	6.27
OA-HC2-C-S5	0.5064	34.8	48.5	13.7	0.5	1.0	3.55	6.12
OA-HC2-O-S1	0.5015	0.0	14.3	14.3	0.5	1.0	3.38	5.83
OA-HC2-O-S2	0.5040	13.5	28.7	15.2	0.5	1.0	3.07	5.29
OA-HC2-O-S3	0.5042	27.7	40.8	13.1	0.5	1.0	3.77	6.49
OA-HC2-O-S4	0.5047	0.6	15.1	14.5	0.5	1.0	3.30	5.68
OA-HC2-O-S5	0.5025	14.5	29.1	14.6	0.5	1.0	3.28	5.65
VG-LC1-C-S1	0.5036	1.2	17.0	15.8	0.5	1.0	2.67	4.60
VG-LC1-C-S2	0.5099	17.0	33.6	16.6	0.5	1.0	2.37	4.09
VG-LC1-C-S3	0.5056	33.6	49.3	15.7	0.5	1.0	2.69	4.64
VG-LC1-C-S4	0.5080	-0.4	16.4	16.8	0.5	1.0	2.31	3.99
VG-LC1-C-S5	0.5018	16.4	32.5	16.1	0.5	1.0	2.58	4.44
VG-LC1-O-S1	0.5091	14.3	29.6	15.3	0.5	1.0	2.80	4.84
VG-LC1-O-S2	0.5065	0.2	16.8	16.6	0.5	1.0	2.39	4.12
VG-LC1-O-S3	-	-	-	-	-	-	-	-
VG-LC1-O-S4	0.5075	15.8	32.5	16.7	0.5	1.0	2.35	4.05
VG-LC1-O-S5	0.5052	33.0	49.5	16.5	0.5	1.0	2.43	4.19
VG-LC2-C-S1	0.5044	17.5	30.8	13.3	0.5	1.0	3.50	6.03
VG-LC2-C-S2	0.5044	30.8	45.5	14.7	0.5	1.0	3.03	5.23
VG-LC2-C-S3	0.5030	0.0	15.0	15.0	0.5	1.0	2.94	5.07
VG-LC2-C-S4	0.5093	15.1	30.0	14.9	0.5	1.0	2.94	5.06
VG-LC2-C-S5	0.5002	30.0	45.7	15.7	0.5	1.0	2.72	4.69
VG-LC2-O-S1	0.5030	32.5	47.6	15.1	0.5	1.0	2.91	5.01
VG-LC2-O-S2	0.5045	14.5	29.6	15.1	0.5	1.0	2.90	4.99
VG-LC2-O-S3	0.5046	29.9	44.1	14.2	0.5	1.0	3.20	5.51
VG-LC2-O-S4	0.5027	-0.5	14.5	15.0	0.5	1.0	2.94	5.07
VG-LC2-O-S5	0.5040	0.2	14.9	14.7	0.5	1.0	3.03	5.23
VG-HC1-C-S1	0.5052	0.0	15.3	15.3	0.5	1.0	2.83	4.87
VG-HC1-C-S2	0.5039	15.3	29.8	14.5	0.5	1.0	3.10	5.35
VG-HC1-C-S3	0.5012	0.2	16.0	15.8	0.5	1.0	2.68	4.62
VG-HC1-C-S4	0.5068	16.0	32.2	16.2	0.5	1.0	2.52	4.34
VG-HC1-C-S5	0.5003	29.8	45.8	16.0	0.5	1.0	2.62	4.52
VG-HC1-O-S1	0.5013	32.2	48.3	16.1	0.5	1.0	2.58	4.45
VG-HC1-O-S2	0.5021	0.0	17.9	17.9	0.5	1.0	1.97	3.40
VG-HC1-O-S3	0.5045	0.0	18.0	18.0	0.5	1.0	1.93	3.33
VG-HC1-O-S4	0.5004	18.3	35.5	17.2	0.5	1.0	2.22	3.82
VG-HC1-O-S5	0.5013	0.0	17.7	17.7	0.5	1.0	2.04	3.52
VG-HC2-C-S1	0.5034	14.5	27.2	12.7	0.5	1.0	3.70	6.39
VG-HC2-C-S2	0.5078	17.8	31.5	13.7	0.5	1.0	3.34	5.76
VG-HC2-C-S3	0.5161	27.6	41.2	13.6	0.5	1.0	3.32	5.72
VG-HC2-C-S4	0.5073	32.0	44.8	12.8	0.5	1.0	3.64	6.28
VG-HC2-C-S5	0.5104	0.0	13.7	13.7	0.5	1.0	3.32	5.73
VG-HC2-O-S1	0.5021	14.1	27.4	13.3	0.5	1.0	3.51	6.06
VG-HC2-O-S2	0.5036	27.6	41.8	14.2	0.5	1.0	3.20	5.52
VG-HC2-O-S3	0.5029	2.0	17.3	15.3	0.5	1.0	2.84	4.90
VG-HC2-O-S4	0.5076	17.4	30.9	13.5	0.5	1.0	3.41	5.88
VG-HC2-O-S5	0.5037	30.9	47.0	16.1	0.5	1.0	2.57	4.43

Code	Weight	V FAS Sample			FAS	$K_2Cr_2O_7$	OC	OM
	g	Intitail	Final	Total	N	N	%	%
PF-LC1-C-S1	0.5057	15.4	30.6	15.2	0.5	1.0	2.82	4.87
PF-LC1-C-S2	0.5130	0.0	14.3	14.3	0.5	1.0	3.08	5.31
PF-LC1-C-S3	0.5033	31.0	46.1	15.1	0.5	1.0	2.87	4.95
PF-LC1-C-S4	0.5021	0.0	15.5	15.5	0.5	1.0	2.74	4.73
PF-LC1-C-S5	0.5025	0.0	16.0	16.0	0.5	1.0	2.57	4.44
PF-LC1-O-S1	0.5099	16.1	32.4	16.3	0.5	1.0	2.44	4.20
PF-LC1-O-S2	0.5008	32.5	48.5	16.0	0.5	1.0	2.58	4.45
PF-LC1-O-S3	0.5034	0.0	15.4	15.4	0.5	1.0	2.77	4.78
PF-LC1-O-S4	-	-	-	-	-	-	-	-
PF-LC1-O-S5	0.5051	15.4	30.7	15.3	0.5	1.0	2.79	4.82
PF-LC2-C-S1	0.5026	31.8	45.6	13.8	0.5	1.0	3.31	5.71
PF-LC2-C-S2	0.5054	0.2	15.1	14.9	0.5	1.0	2.93	5.04
PF-LC2-C-S3	0.5011	15.1	30.2	15.1	0.5	1.0	2.88	4.97
PF-LC2-C-S4	0.5005	30.2	43.7	13.5	0.5	1.0	3.42	5.90
PF-LC2-C-S5	0.5000	0.0	15.9	15.9	0.5	1.0	2.62	4.52
PF-LC2-O-S1	0.5053	15.5	29.7	14.2	0.5	1.0	3.16	5.45
PF-LC2-O-S2	0.5096	-0.2	15.3	15.5	0.5	1.0	2.70	4.66
PF-LC2-O-S3	0.5042	29.7	44.0	14.3	0.5	1.0	3.13	5.40
PF-LC2-O-S4	0.5019	0.0	13.9	13.9	0.5	1.0	3.28	5.66
PF-LC2-O-S5	0.5089	13.3	26.9	13.6	0.5	1.0	3.33	5.75
PF-HC1-C-S1	0.5095	28.6	41.7	13.1	0.5	1.0	3.50	6.03
PF-HC1-C-S2	0.5002	15.4	30.1	14.7	0.5	1.0	3.02	5.21
PF-HC1-C-S3	0.5051	30.1	45.7	15.6	0.5	1.0	2.69	4.64
PF-HC1-C-S4	0.5025	15.3	31.5	16.2	0.5	1.0	2.51	4.32
PF-HC1-C-S5	0.5045	31.5	47.4	15.9	0.5	1.0	2.60	4.48
PF-HC1-O-S1	0.5050	0.0	16.0	16.0	0.5	1.0	2.56	4.42
PF-HC1-O-S2	0.5039	18.7	36.0	17.3	0.5	1.0	2.13	3.68
PF-HC1-O-S3	0.5062	36.0	53.0	17.0	0.5	1.0	2.22	3.83
PF-HC1-O-S4	0.5012	16.0	32.8	16.8	0.5	1.0	2.31	3.99
PF-HC1-O-S5	0.5086	32.9	50.2	17.3	0.5	1.0	2.11	3.64
PF-HC2-C-S1	-	-	-	-	-	-	-	-
PF-HC2-C-S2	0.5011	12.2	25.2	13.0	0.5	1.0	3.59	6.18
PF-HC2-C-S3	0.5072	0.0	12.7	12.7	0.5	1.0	3.64	6.28
PF-HC2-C-S4	0.5023	25.2	38.7	13.5	0.5	1.0	3.41	5.88
PF-HC2-C-S5	0.5000	16.2	29.0	12.8	0.5	1.0	3.66	6.31
PF-HC2-O-S1	0.5074	0.0	15.5	15.5	0.5	1.0	2.72	4.68
PF-HC2-O-S2	0.5095	29.0	43.4	14.4	0.5	1.0	3.07	5.29
PF-HC2-O-S3	0.5035	18.7	34.3	15.6	0.5	1.0	2.70	4.66
PF-HC2-O-S4	0.5029	34.3	46.9	12.6	0.5	1.0	3.71	6.39
PF-HC2-O-S5	-	-	-	-	-	-	-	-
MT-LC1-C-S1	0.5023	13.8	29.0	15.2	0.5	1.0	3.01	5.19
MT-LC1-C-S2	0.5089	13.3	29.7	16.4	0.5	1.0	2.57	4.44
MT-LC1-C-S3	0.5094	27.2	42.5	15.3	0.5	1.0	2.94	5.06
MT-LC1-C-S4	0.5095	0.0	13.8	13.8	0.5	1.0	3.43	5.91
MT-LC1-C-S5	0.5043	13.2	27.0	13.8	0.5	1.0	3.46	5.97
MT-LC1-O-S1	0.5022	0.0	13.7	13.7	0.5	1.0	3.51	6.06
MT-LC1-O-S2	0.5055	29.5	43.7	14.2	0.5	1.0	3.32	5.73
MT-LC1-O-S3	0.5007	0.0	14.4	14.4	0.5	1.0	3.29	5.67
MT-LC1-O-S4	0.5012	0.0	14.9	14.9	0.5	1.0	3.12	5.37
MT-LC1-O-S5	0.5058	0.0	14.3	14.3	0.5	1.0	3.29	5.67
MT-LC2-C-S1	0.5018	0.0	13.4	13.4	0.5	1.0	3.62	6.23
MT-LC2-C-S2	0.5055	0.0	13.3	13.3	0.5	1.0	3.62	6.25
MT-LC2-C-S3	0.5078	14.9	26.9	12.0	0.5	1.0	4.04	6.96
MT-LC2-C-S4	0.5034	13.7	26.8	13.1	0.5	1.0	3.70	6.39
MT-LC2-C-S5	0.5090	0.0	13.3	13.3	0.5	1.0	3.60	6.20
MT-LC2-O-S1	0.5093	29.7	43.3	13.6	0.5	1.0	3.50	6.03
MT-LC2-O-S2	0.5060	30.0	45.1	15.1	0.5	1.0	3.02	5.21
MT-LC2-O-S3	0.5040	14.3	29.3	15.0	0.5	1.0	3.07	5.29
MT-LC2-O-S4	0.5058	14.4	27.7	13.3	0.5	1.0	3.62	6.24
MT-LC2-O-S5	0.5046	0.0	14.7	14.7	0.5	1.0	3.16	5.45
MT-HC1-C-S1	0.5027	29.7	44.2	14.5	0.5	1.0	3.24	5.59
MT-HC1-C-S2	0.5087	0.0	14.5	14.5	0.5	1.0	3.20	5.52

Code	Weight	V FAS Sample			FAS	$K_2Cr_2O_7$	OC	OM
	g	Intitail	Final	Total	N	N	%	%
MT-HC1-C-S3	0.5092	29.5	46.6	17.1	0.5	1.0	2.34	4.04
MT-HC1-C-S4	0.5026	13.2	27.2	14.0	0.5	1.0	3.41	5.88
MT-HC1-C-S5	0.5052	26.2	39.9	13.7	0.5	1.0	3.49	6.02
MT-HC1-O-S1	0.5008	0.0	15.8	15.8	0.5	1.0	2.82	4.86
MT-HC1-O-S2	0.5072	14.9	32.9	18.0	0.5	1.0	2.05	3.54
MT-HC1-O-S3	0.5054	13.4	26.2	12.8	0.5	1.0	3.79	6.53
MT-HC1-O-S4	0.5024	0.0	14.8	14.8	0.5	1.0	3.14	5.42
MT-HC1-O-S5	0.5032	32.9	47.6	14.7	0.5	1.0	3.17	5.47
MT-HC2-C-S1	0.5054	26.0	37.5	11.5	0.5	1.0	4.22	7.28
MT-HC2-C-S2	0.5064	26.8	38.5	11.7	0.5	1.0	4.15	7.15
MT-HC2-C-S3	0.5071	26.0	38.0	12.0	0.5	1.0	4.04	6.97
MT-HC2-C-S4	0.5059	27.0	37.4	10.4	0.5	1.0	4.58	7.90
MT-HC2-C-S5	0.5025	26.9	38.2	11.3	0.5	1.0	4.31	7.44
MT-HC2-O-S1	0.5071	15.8	30.0	14.2	0.5	1.0	3.31	5.71
MT-HC2-O-S2	0.5048	14.7	29.5	14.8	0.5	1.0	3.13	5.39
MT-HC2-O-S3	0.5037	0.0	13.2	13.2	0.5	1.0	3.67	6.33
MT-HC2-O-S4	0.5026	29.3	44.1	14.8	0.5	1.0	3.14	5.42
MT-HC2-O-S5	0.5083	14.5	29.7	15.2	0.5	1.0	2.97	5.13

BIOGRAPHY

Mongkolchai Assawadithalerd was born on the 25th April, 1982 in Bangkok, Thailand. He graduated at the King Mongkut's Institute of Technology North Bangkok, Faculty of Applied Science, Bachelor of Agro – Industrial Technology (Environmental Technology) in 2004 Then, he continued his further education for the Master Degree at the International Post-graduated Program in Environmental Management, a joint program of National Center of Excellence for Environmental and Hazardous Waste Management (NCE-EHWM) in May 2008.

Proceedings:

1. Assawadithalerd, M., Chanthawong, C. and Songthanasak, K. Preliminary Feasibility Study on Removal Pb^{2+} in Synthetic Wastewater using Composted Bagasse as Adsorbent, (Poster presentation). 1st IWA ASPIRE 2005, July, 10-15, 2005, Pan Pacific Hotel, Singapore.
2. Mongkolchai Assawadithalerd, Chantra Tonhcumpou, Meechai Siangliw. Effects of Organic Fertilizer on Cd and Zn Bioavailability in Paddy Soil. (Oral Presentation). The Second Conference on Environmental Science, Engineering and Management – CESEM 2010, March, 18-19, 2010, Bangkok, Thailand.