โครงการ
การเรียนการสอนเพื่อเสริมประสบการณ์

ชื่อโครงการ Spatial variability of available micronutrients in burning and non-burning paddy soils

ชื่อนิสิต Miss Boonyaporn Juethong

ภาควิชา Environment Science
ปีการศึกษา 2018

คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

SENIOR PROJECT

Project Title **Spatial variability of available micronutrients in burning and non-burning paddy soils**

Student Name Miss Boonyaporn Juethong Student ID 583 33256 23

Department Environment Science

Academic Year 2018

Faculty of Science, Chulalongkorn University

Spatial variability of available micronutrients in burning and non-burning paddy soils

ความผันแปรเชิงพื้นที่ของธาตุอาหารเสริมที่เป็นประโยชน์ต่อพืชในดินนาข้าวที่มีการเผาและไม่เผา

Boonyaporn Juethong

A Senior Project Submitted in Partial Fulfillment of the Requirement for the
Degree of Bachelor of Science Program in Environmental Science Faculty of Science,
Chulalongkorn University, Academic Year 2018

Project Title Spatial variability of available micronutrients in burning and non-burning paddy soils

Student name Miss Boonyaporn Juethong Student ID 583 33256 23

Project advisor Assistant Professor Pasicha Chaikaew, Ph.D.

Department Environmental Science

Academic year 2018

Accepted by the Department of Environmental Science, Faculty of Science, Chulalongkorn University in Partial Fulfilment of the Requirements for the Bachelor's Degree.

.... Head of the Department of Environmental Science

(Professor Dr. Wanida Jinsart, Ph.D)

PROJECT COMMITTEE

....

(Assistant Professor Sarawut Srithongouthai, Ph.D.) Chairman

....

(Assistant Professor Pantana Tor-ngern, Ph.D.) Committee

Chidsanuphong Chart-asa

(Chidsanuphong Chart-asa, Ph.D) Committee

....

(Assistant Professor Pasicha Chaikaew, Ph.D.) Project advisor

หัวข้อ ความผันแปรเชิงพื้นที่ของธาตุอาหารเสริมที่เป็นประโยชน์ต่อพืชในดินนาข้าวที่มีการเผาและไม่เผา
โดย นางสาวบุณยาพร เจือทอง รหัสประจำตัวนิสิต 583 33256 23
อาจารย์ที่ปรึกษา ผู้ช่วยศาสตราจารย์ ดร.ภศิชา ไชยแก้ว
ภาควิชา วิทยาศาสตร์สิ่งแวดล้อม
ปีการศึกษา 2561

บทคัดย่อ

ในประเทศไทยมีวิธีการจัดการฟางข้าวในพื้นที่นาโดยวิธีการเผาในพื้นที่เปิดโล่งเพื่อเป็นการเตรียมความพร้อมสำหรับการเพาะปลูกในครั้งต่อไป ซึ่งยังมีข้อสงสัยถึงผลกระทบของการจัดการโดยการเผาต่อความเข้มข้นธาตุอาหารเสริมที่เป็นประโยชน์ต่อพืชที่มีอยู่ในดินนาข้าว โดยการศึกษานี้มีวัตถุประสงค์เพื่อ 1.เปรียบเทียบความเข้มข้นของธาตุอาหารเสริมทองแดง, เหล็ก, แมงกานีส และสังกะสี ที่เป็นประโยชน์ต่อพืช ระหว่างพื้นที่นาที่มีการจัดการโดยการเผา และไม่เผา 2.ประเมินความสัมพันธ์ของธาตุอาหารเสริมที่เป็นประโยชน์ต่อพืชกับคุณสมบัติของดิน 3.ทำแผนที่แสดงการกระจายตัวเชิงพื้นที่ของธาตุอาหารเสริมที่เป็นประโยชน์ต่อพืชของพื้นที่นาที่มีการเผา และไม่เผา วิธีการเก็บตัวอย่างดินดำเนินการโดยเก็บตัวอย่างดินนา 2 ชุดตัวอย่าง จำนวนทั้งหมด 40 ตัวอย่าง โดยตัวอย่างนาเผาเก็บตัวอย่างจากนาข้าวที่มีการเผาอย่างน้อย 5 ปี ติดต่อกัน และตัวอย่างนาไม่เผา ชุดละ 20 ตัวอย่าง ที่ระดับความลึก 30 เซนติเมตร ซึ่งวิเคราะห์ความเข้มข้นของธาตุอาหารเสริมทองแดง, เหล็ก, แมงกานีส และสังกะสี ที่เป็นประโยชน์ต่อพืช โดยวิธีการสกัดด้วย diethylenetriaminepentaacetic acid (DTPA) จากการศึกษาพบว่าค่าเฉลี่ยของธาตุอาหารเสริมที่เป็นประโยชน์ต่อพืชมีค่าเรียงจากมากไปน้อยดังนี้ เหล็ก>แมงกานีส>ทองแดง>สังกะสี ความเข้มข้นของธาตุอาหารเสริมทองแดง, เหล็ก และแมงกานีส ที่เป็นประโยชน์ต่อพืช นั้นเพียงพอต่อการเพาะปลูกข้าว โดยในพื้นที่นาเผานั้นมีความเข้มข้นของธาตุอาหารเสริมมากกว่าพื้นที่นาที่ไม่เผาอย่างมีนัยสำคัญ จากผลการศึกษาพบว่าพื้นที่ดินนาทั้งสองพื้นที่ขาดธาตุสังกะสีที่เป็นประโยชน์ต่อพืช ดังนั้นจึงควรมีแนวทางในการปรับปรุงปริมาณธาตุสังกะสีที่เป็นประโยชน์ต่อพืชในพื้นที่นา

คำสำคัญ : ธาตุอาหารเสริมที่มีประโยชน์ต่อพืช, การเผา, ดินนาข้าว

Project Title Spatial variability of available micronutrients in burning and non-burning paddy soils

Student name Miss Boonyaporn Juethong Student ID 583 33256 23

Project advisor Assistant Professor Pasicha Chaikaew, Ph.D.

Department Environmental Science

Academic year 2018

Abstract

An open burning in paddy field is a conventional way to remove stubbles and prepare for the next crop cycle, yet a controversial issue about available micronutrients in soils remains, in particular, in a long-term burned field. This study aimed to i) compare available concentrations of Cu, Fe, Mn and Zn between burning and non-burning paddy soil, ii) assess the relationship of micronutrient availability and soil properties, iii) map the spatial distribution of soil micronutrients. Two sets of soil samples, a total of 40, were collected from two paddy fields based on minimum consecutive five-year periods of burning versus non-burning practices. Available Cu, Fe, Mn and Zn were obtained by diethylenetriaminepentaacetic acid (DTPA) extraction method. Mean available micronutrients were as follows: Fe>Mn>Cu>Zn. Abundant concentrations of Cu, Fe, and Mn were sufficient for growing rice in both sites; however, they were significantly greater in burning paddy field as compared to non-burning field. Zn deficiency occurred across paddy farming soils. On the basis of results obtained, Strategies to improve Zn availability are required.

Keywords: Available micronutrients, Burning practice, Paddy soil

ACKNOWLEDGEMENTS

This project accomplishes because I have received plentiful of helps and support many individuals and organizations. So, I would like to express my very great appreciation to who contributed to this work.

Foremost, I would like to express my sincere gratitude to my project advisor, Assistant Professor Pasicha Chaikaew, Ph.D., Department of Environmental Sciences, Faculty of Science, Chulalongkorn University for guidance, patience, enthusiastic, encouragement, knowledge and caring.

I would like to thank my research chairman, Assistant Professor Sarawut Srithongouthai, Ph.D. and our project committee, Assistant Professor Pantana Tor-ngern, Ph.D., Chidsanuphong Chart-asa, Ph.D and thank for their comments and suggestions.

I would like to thank Mrs Jutamat Thiangtam, Mr Anan Thethan, the Land Development Regional office 1, the Department of Environmental Science, Faculty of Science, Chulalongkorn University and also people in this organization for providing me with all the necessary facilities for the research.

In addition, I would like to give a thanks to Miss Thanaporn Naka, Mr Phanupong Wongchan for laboratory support and useful guidance throughout my laboratory analysis and to all my friend who support both force and inner strength.

Finally, I am grateful to my parents for their endless support and encouragement. Thank you so much.

CONTENTS

Page

CONTENTS (continue)

Page

CONTENTS (continue)

Page

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1. Introduction

Approximately 162.3 million hectares of land around the world are dedicated for rice cultivation, producing more than 738.1 million tons of rice grain and providing more than half of the daily dietary calories for the world's population. Asian countries such as India, Thailand, and Vietnam are the main countries involved in rice trade (Prasad, 2016). Rice production ecosystems in Thailand can be classified into four categories. Rainfed lowland is the most predominant, followed by irrigated, deepwater, and upland. Saraburi province, located in the central region, is considered an intensively cultivated alluvial area. Agricultural area covers about 40% of the province, mostly rainfed and irrigated ecosystem practices. Of the four groups of land suitability (highly, moderately, marginally, and suitable for growing other crops), Nong Don and Phra Phuttabat districts are classified as highly suitable area for rice farming and suitable for growing other crops (Pathumthani rice research, 2009).

Despite the positive suitability for rice growing, natural soils in these districts are calcareous with high $CaCO_3$. Calcareous soils worldwide suffer from micronutrient deficiencies because they limit plant growth. Micronutrients are typically found in cofactors and coenzymes (Daintith and Martin, 2010). Copper (Cu) is necessary for carbohydrate and nitrogen metabolism as well for lignin synthesis in cell wall. Many soils especially the leached, sandy, and excessively cropped soils-need Cu applications for optimum crop production, and highly organic soils are also often deficient in Cu.

Iron (Fe) is involved in chlorophyll formation and acts as a catalyst in plant growth. Lack of sufficient Fe in plants results in yellowing of the plant. Manganese (Mn) is another essential micronutrient associated with Fe and has similar functions in the plant. Available Mn is often deficient in agricultural soil. Mn, Cu, and Fe are probably the main oxidation- reduction regulators in plants. Zinc (Zn) in plant nutrition is associated with the role of Cu, mainly as a coenzyme, Zn fertilizers are mainly applied to corn and rice. Micronutrient sources vary considerably in physical, chemical and availability to plants (Kogel et al., 2006). Corn plantation in calcareous soils often face the deficit of Zn and Fe (FAO). Lowland rice, in addition, often encounters a lack of Zn and Cu (Kausar et al., 1976).

Many countries in Asia, open burning of rice stubble after harvesting for agricultural land clearing is commonly practiced. Plenty of soil nutrients are removed in agricultural areas. This has significant implications for maintaining the long-term nutrient balance in soils. Burning crop residues in shifting cultivation caused the loss of nitrogen through combustion process, while products from burning like ash is a good source of micronutrients, i.e. Cu, Zn, Mn, Na, and Si (Abdul et al., 2004; Du Preez et al., 2001). When cationic micronutrients in soil increased after burning, the plant-available Fe, Cu, and Zn concentrations decreased, and Mn increased (Venkatesh et al., 2003) After a long-term burning treatment, Cu and Zn are prone to leach from ash and loss from erosion (Abdul et al., 2004). Up to our knowledge, there are gaps missing in the existing research literature. The study of micronutrients in Thailand calcareous paddy soils is lacking as well as the comparison between a long period of burning and non-burning treatments. To address these challenges, we aimed to quantify the existing

Cu, Fe, Mn, and Zn concentrations in paddy fields and link information with other soil properties and suitability of micronutrients for growing rice.

1.2 Objectives

1.2.1 To compare available concentrations of Cu, Fe, Mn and Zn between burning and non-burning paddy soil.

1.2.2 To assess the relationship of micronutrient availability and soil properties.

1.2.3 To map the spatial distribution of soil micronutrient concentration.

1.3 Outcome of research

1.3.1 The database of micronutrient availability and soil properties from burning and non-burning paddy soil can be useful in future soil conservation plan.

1.3.2 The spatial distribution enables us to obtain a better understanding information of soil micronutrient concentration in a large scale.

CHAPTER II

LITERATURE REVIEW

2.1 Micronutrients

Micronutrients are commonly found as component of cofactors and coenzymes in living organisms. It is essential for plant growth and play an important role in balance crop nutrition such as Copper (Cu), Iron (Fe), Manganese (Mn) and Zinc (Zn). Micronutrient concentrations are generally higher in the surface soil and decrease with soil depth. In spite of the high concentration of most micronutrients in soils, only a small fraction is available to plants (Gupta et al., 2008). Micronutrients released from minerals by weathering processes during soil formation and subsequent development become associated with and accumulate in the soil. The adsorption behavior of soils is almost certainly due to the soil colloidal components, which can be conveniently grouped into three categories: layer silicate clays, oxides and organic matter (Swift and McLaren, 1991). Micronutrients have immense economic importance since an adequate supply of micronutrients can help to ensure better yields. Application of micronutrients in association with N, P, K and S showed better performance in respect of grain yield and yield contributing characters. The performance of Zn and Cu with N, P, K and S was the best for improving the growth and yield of rice (Nadim et al., 2011). The interaction of Mn inside the plant and the absorption sites could be physiological in nature because low Mn levels are necessary for efficient utilization of Fe. The maximum dry matter yield was obtained at lower levels of Fe and Mn than at the higher levels. This may be due to the fact that at the higher levels these nutrients interact in the plant root system, inhibiting their utilization by the rice plant and resulting in the reduction of dry matter yield (Alam, 1985).

2.1.1 Copper (Cu)

Copper is necessary for carbohydrate, nitrogen metabolism and lignin synthesis in cell wall. Many soils especially the leached, sandy and excessively cropped soils need Cu applications for optimum crop production and highly organic soils are also often deficient in Cu (Kogel et al., 2006). Plants absorb copper from the soil solution as Cu^{2+} ions, probably also in the form of low-molecular organic complexes and sometimes from inorganic complexes. Cu deficiency symptoms include chlorosis and pale yellow and white colored leaves, curled and withered leaf tips, and yield losses. Cu excess can have toxic effects on plants. The majority of Cu fixed on Mn and Fe oxides and organic matter is very firmly bound and in a form that is difficult to adsorb. For this reason, the portion of the exchangeable Cu^{2+} in the total Cu is generally low at pH values >5 (Blume et al., 2016). In soil minerals it may substitute Fe^{2+}. A substantial proportion of Cu in soils is present in organic complexes. Cu mobility is restricted to acid, oxidizing environments (Hossner et al., 2008).

2.1.2 Iron (Fe)

Fe is present in soils in huge quantities but its solubility is very low (Lindsay, 1991) . In general Fe and Mn are slightly soluble and therefore relatively immobile, in well aerated soil environments, becoming soluble and mobile under lower redox conditions or at high acidities (Hossner et al., 2008). Fe is involved in chlorophyll formation and acts as a catalyst in plant growth. Lack of sufficient Fe in plants results in yellowing of the plant (Kogel et al., 2006). Plants requirements mainly from organic

Fe^{2+} and Fe^{3+} complexes that are present in the soil solution. Fe^{3+} is reduced to Fe^{2+} on the root surface and then absorbed. Under anoxic conditions after reduction of Fe^{3+} oxides to Fe^{2+} ions, there may be high Fe^{2+} concentrations in the soil solution and in the groundwater. Under aerobic conditions, the Fe availability in soils is mainly determined by interactions between poorly crystallized Fe^{3+} oxides and soluble organic complexing ligands, which form soluble Fe (II, III) complexes. Fe deficiency is relatively widespread around the world in soils containing $CaCO_3$, despite generally high Fe oxide contents. In addition, it can occur when the soil is limed to pH >7. In calcareous soils, especially in wet phases, an important cause for this is the high HCO^{3-} concentration in the soil solution, which cause Fe immobilization in the plant through various physiological effects (Blume et al., 2016).

2.1.3 Manganese (Mn)

The concentration of plant-available Mn^{2+} in the soil solution depends to a great extent on the soil pH, on the redox conditions, and on the reserves of active Mn in the soil. When the Mn^{2+} concentrations are too low, plants can sometimes initiate mobilization of Mn^{2+} through the excretion of root. In temperate humid climate regions, Mn deficiency is observed particularly on Mn-poor sandy soils and drained fens at pH ≥ 6, as well as on calcareous soils (Blume et al., 2016). The forms of Mn in soils is mostly limited to the Mn oxides that occur in calcareous soils. The nature of the weathering solid Mn^{2+} is present as a minor or trace element in isomorphous substitution for Fe (Hossner et al., 2008). Manganese is essential micronutrient associated with Fe and has similar functions in the plant. Available Mn is often deficient in agricultural soil (Kogel et al., 2006). Most Mn minerals in rocks have crystallized under reducing conditions and where little free water is available for inclusion into mineral structures. Some of the Mn in soils can exist in solution, some may be adsorbed the surfaces of minerals and organic matter or be incorporated into organisms but most is likely to be a constituent of primary and secondary minerals (Gilkes and McKenzie, 1988).

2.1.4 Zinc (Zn)

The primary source of Zinc is the sulfide, sphalerite (ZnS), though most Zn in the lithosphere is present as an isomorphous replacement of Fe in the ferromagnesian minerals. Normally Zn^{2+} will be released into the environment when the sphalerite break down (Hossner et al., 2008). The exchangeable Zn contents are very low at pH values > 6. With decreasing pH, the proportion of this fraction in the total replenishable Zn strongly increases. Zn deficiency with clear deficiency symptoms is mostly restricted to soils containing carbonates. However, Zn deficiency is relatively frequent worldwide in semi-humid to arid regions on alkaline soils with high contents of fine-grained $CaCO_3$. In these cases, the Zn availability is mainly reduced by high pH values. the spreading of iron oxides can cause additional Zn fixation. Zn uptake by plants can also be lowered by high phosphate fertilization (Blume et al., 2016). Characterizing zinc availability provides important information on the pool size of Zn potentially available for uptake. Concentrations of Zn in soil solution at high soil pH are very low and mobility, transport to the root surface are usually rate limiting factors of soil supply (Barrow 1993). Zn distribution and transport in plants is affected by the level of Zn supply and plant species. Zn in plant nutrition is associated with the role of Cu, mainly as a coenzyme (Kogel et al., 2006).

2.2 Soil properties

Soil properties determine many key soil processes and the agronomical potential of a soil. A proper understanding of soil characteristics and adequate interpretation of the magnitudes of its properties, both combined under the broader term of soil quality, is required for proper management of agricultural soils.

2.2.1 pH

Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H^+) in the soil. In Thailand, soil pH in H_2O for the topsoil averages 6.0±1.0 and 6.4±1.1 for subsoil (Prakongkep et al., 2008). The availability of micronutrients Cu, Fe, Mn and Zn tend to decrease as soil pH increases but for the majority of soils and crops this decrease is not concern until soil pH is greater than 8 (Ross, 2015). In flooding condition, a decrease in pH of alkali or calcareous soils is the result of accumulation of carbon dioxide in flooded soil, which neutralizes alkalinity. Moreover, carbon dioxide produced is retained in the flooded soil due to restricted diffusion through standing water on the soil surface. This allows large quantities of carbon dioxide to accumulate and form mild acid, which helps in neutralizing alkalinity in the soil-floodwater system. Moreover, the submerged soil system provides an ideal environment for reaction between carbon dioxide (carbonic acid) and alkalinity (Ponnamperuma, 1972; Sahrawat, 2004). The pH scale ranges from approximately 0 to 14 with 7 being neutral, below 7 acidic, and above 7 alkaline. Soil pH can affect CEC by altering the surface charge of colloids. A higher concentration of H^+ (lower pH) will neutralize the negative charge on colloids, thereby decreasing CEC.

2.2.2 Organic matter

Organic matter is the material in soil that is directly derived from plants and animals, and it supports most important microfauna and microflora in the soil. Soil organic matter described a wide range of organic components in the soil including living and non-living organic materials. The non-living organic matter can be broken down into dissolved organic matter, particulate organic matter, humus and inert organic matter (Hazelton and Murphy, 2007). Organic soils are dark grey or black in color. They usually have a characteristic odor of decay and feel spongy when wet, compared to inorganic clays. The tendency for soils with significant organic content to create voids by decay, or to change the physical characteristics of a soil mass through chemical alteration (Hazelton and Murphy, 2011).

2.2.3 Texture

Texture refers to the relative proportions of particles of various sizes such as sand, silt and clay in the soil. Thailand paddy soils, as part of the central region, have a heavy texture (silty clay to clay) (Prakongkep et al., 2008). The proportions of the separates in classes commonly used in describing soils are given in the textural triangle. Soil texture can influence whether soils are free draining, whether they hold water and how easy it is for plant roots to grow. Soil texture can influence grain yield. Clay soil that is favorable in retaining water and nutrients than sandy soil is desirable in obtaining higher grain yield. Clay soil produced more tillers and grains, heavier seeds and better grain filling relative to sandy soil. Soil texture indicated that cultivar selection and soil condition are important factors in deciding what water management option to practice (Dou et al., 2016).

2.2.4 Cation exchange capacity (CEC)

Cation exchange capacity is the capacity of the soil to hold and exchange cations. It is a major controlling agent of stability of soil structure, nutrient availability for plant growth, soil pH, and the soil's reaction to fertilizers and other ameliorants. A low CEC means the soil has a low resistance to changes in soil chemistry that are caused by land use. CEC of different fraction within the soil, including different sized particles, clays, soil minerals and soil organic matter. Soils with high amounts of clay can have high cation exchange capacity (Hazelton and Murphy, 2016).

2.2.5 Electrical conductivity (EC)

Soil electrical conductivity is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity, drainage conditions, organic matter level, salinity, and subsoil characteristics. EC is the most common measure of soil salinity and is indicative of the ability of an aqueous solution to carry an electric current. Plants are detrimentally affected by excess salts in some soils and by high levels of exchangeable sodium in others. The electrical conductivity of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity. Consequently, EC correlates strongly to soil particle size and texture (NCCP, 2018).

2.3 Rice paddies

Rice is the best-known wetland crop. Paddy systems have persisted, their efficient productivity and retention of water, soil and nutrients leading to common implementation across much of the tropical and subtropical world. Paddies can be built as terraces, sometimes engineered by dependent communities as an efficient means to sustain themselves while conserving water, soil, and nutrients (Everard, 2016). Rice paddy farming systems vary depending upon the topography and ecological condition of each country and region, not to mention the culture and customs of the populations and villages. In the Mainland Southeast Asia (MSEA) countries, whether it is rainfed, irrigated, or floating rice in lowlands or uplands, paddy farming is water driven and labor-intensive which Thailand is one of the MSEA countries. The central plain is a lowland area drained by the Chao Phraya River and its tributaries making a fertile basin for wet rice agriculture. Basically, paddy farming system consists of three stages (land preparation, rice planting and rice harvests) (Cosslett and Cosslett, 2018).

2.4 Crop residual

The generated crop residues will be left in the field after harvesting. The amounts of residues which should be left will depend on the soil type and structure, crop rotation, tillage system and existing conservation practices. The residues can improve soil fertility by providing macro- and micro-nutrients, preventing erosion by stabilizing the top layers of the soil and increasing soil organic matter that are essential for maintaining the nutrient cycles (FAO, 2014). In other hand, crop residue burning of farm waste causes severe pollution of land and water on local as well as regional scale. It has adverse consequences on the quality of soil. When the crop residue is burnt the existing minerals present in the soil get destroyed which adversely hampers the cultivation of the next crop (Kumar and Joshi, 2013). The micronutrient contents in rice straw, without organic manure, were found 1.10 ppm Cu, 57.96 ppm Fe, 11.90 ppm Mn and 17.70 ppm Zn by Baishya et al. (2016) and Jeng et al (2012) found 0.85% of Fe_2O_3 in rice straw ash when the weight of uncompressed rice straw is about 70 to 80 kg/m^3 at a moisture content of about 15 to 18%.

2.5 Related research

Chemical fractions of soil micronutrients can be classified into 4 fractions (residual, oxidizable, reducible and exchangeable). In semi-arid agroecosystems, central India, Cu, Fe and Zn are dominant fraction while Mn was found as reducible fraction in paddy soils. Reducible fraction could be easily available to plants by significant release from Fe/Mn oxy-hydroxides due to anaerobic conditions caused by flooding, conventional and no-tillage. Available fractions of micronutrients are found in the range of less than 20%-70% in soil agricultural intensification. Irrigated paddy soils has higher concentrations of exchangeable fraction than rained paddy soils (Shukla and Anshumali, 2018).

In southern China, many of the areas dominated by acid sulfate (AS) soils have been reclaimed for rice cultivation and represent an important source of agricultural production. Rice cultivation significantly reduced acidity levels at soil depths of 0–100 cm and increased acidity at depths of 100–140 cm. A substantial loss of Mn in the oxide and acidified soil layer (0–100 cm), but there were few changes in the concentrations of Fe and Zn throughout the soil profile. In general, leaching of Fe, Mn was higher in the paddy fields because of enhance irrigation and flood conditions, whereas accumulation of Cu, mainly in the form of acid soluble and crystalline iron oxide. Cu was higher in the paddy fields than in the uncultivated fields (Haung et al., 2017).

Steep slopes and very high rainfall concentrated within a few months suggest that the practice of slash-and-burn agriculture will induce severe erosion losses. 2 years of study soil composition and erosion comparing a shifting cultivated catchment and a neighboring non-burnt catchment showed an additional loss by runoff of about 30 Mg ha^{-1} of upland soil, containing substantial amounts of plant nutrients as a result of burning. The main loss occurred within 2 to 3 months after burning, but after 1 year, losses in the shifting cultivated catchment were the same as in the non-burnt catchment. The ash from the burnt vegetation was found to add more available Fe, Mn, and Zn to the soil than was removed in runoff sediments, whereas soil Cu contents decreased. The high clay contents and the horizontal and vertical uniformity are clear indicators of intensive and fast weathering (Gafur et al., 2004).

Soil fertility indicators were influenced by the application of different residue management practices in a field trial near Bethlehem in South Africa. After 11–12 years, only pH, K, P and Zn were significantly influenced by the residue management practices. Straw burning and conservational tillage increased the levels of those four indicators when compared with no burning and conventional tillage. A thorough investigation into the plant availability of the K, P and Zn that accumulated in the upper 50 mm soil as a result of either straw burning or conservational tillage (Du Preez et al., 2001).

Burning surface soil samples under terrace cultivation resulted in decrease of available Fe, Zn and Cu, whereas available Mn and total micronutrients increased on burning and a maximum increase was recorded in total Mn due to addition of these cations through burning of dry biomass. The level of available and total micronutrients after 3 years of terrace cultivation was almost similar to their initial status. Highest amount of available forms of Fe, Zn and Cu and least amount of available Mn were noticed in valley land. Organic carbon content was positively correlated with available Zn and Cu. The importance of fire in slash and burn agriculture is seen from the fact that these is a quick release of cations after burning in surface soils (Venkatesh et al., 2003).

CHAPTER III

METHODOLOGY

3.1 Study area

The study area was conducted in the Nong Don and Phra Phutthabat district, Saraburi province, Thailand. Saraburi is on the east side of the Chao Phraya River valley. The western part is mostly low, flat plains. The Nong Don district extends between 14°40′52″N latitude and 100°42′30″E longitude and a land cover of 88.07 km^2 that neighbouring districts are (from the north clockwise) Mueang Lop Buri of Lopburi Province, Phra Phutthabat, Ban Mo and Don Phut of Saraburi Province. The Phra Phutthabat district extends between 14°43′32″N latitude and 100°47′43″E longitude and a land cover of 287.1 km^2 that Neighboring districts are (clockwise from the north) Mueang Lop Buri and Phattana Nikhom of Lopburi Province, and Chaloem Phra Kiat, Sao Hai, Ban Mo, Nong Don. The burning paddy soil is in the Nong Don district. The paddy field was added the chemical fertilizer and the area was burned after harvesting. The non-burning paddy soil is in the Phra Phutthabat district. The paddy field was added the green manure before rice transplanting resulted in significant improvement in paddy yield over that in the non-green manured plots. The increase in micronutrients, particularly Fe, Mn and organic carbon seemed to be responsible for increased rice yields (Nayyar, 2000). The area was stubble plowed after harvesting in which it can accelerate the decomposition of soil organic matter and leave the soil susceptible to wind and water erosion.

The topography of Saraburi area is defined by the central basin plains and Dong Phaya Yen mountains. In south east and west is plains and the height of sea level is 2 m. The central area has a high slope which is plain and hilly. It is located north and north east of the province. Nong Don district is plain characteristic which is part of the Chao Phraya River basin. Phra Phutthabat district is plateau characteristic which have hill, monadnock and plateau. The height of sea level is 100-500 m. During the dry season, the weather is intensive hot and arid.

The climate is tropical savanna depends on 2 monsoons, which blow from the north east in the winter called the northeast monsoon. The weather is dry and quite cold in winter and quite hot in summer. Another monsoon is South west winds from the south. South west lead to a moist and rainy climate. Weather is divided into 3 seasons as Summer starts from mid-February to mid-May. During this period is a monsoon-free, but there will be winds from the south and south east lead to hot and humid. April is the hottest month. Rainy season starts from mid-May to mid-October. It depends on the southwest monsoon which the wind blows moisture and steam from the Indian ocean from the south west. Winter starts from mid-October to mid-February. It depends on the north east monsoon lead to cold and drought from the north east and December and January are the coldest month.

Fig.1 Map of the study area showing sampling locations of burning paddy soil in Nong Don district (n=20) Satellite source: Google Earth. (November 17, 2018). Saraburi Province (Accessed April 16, 2019).

Fig.2 Map of the study area showing sampling locations of non-burning paddy soil in Phra Phutthabat district (n=20) Satellite source: Google Earth. (November 17, 2018). Saraburi Province (Accessed April 16, 2019).

3.2 Sampling and preparation

A total of 40 geo-referenced sampling station were selected to collect surface soil after harvested of paddy-crops in April 2018. The latitude, longitude for each sampling point were recorded using a handheld Global Positioning System (GPS). Sampling station were classified as burning paddy soil sites (n=20) and non-burning paddy soil sites (n=20). The samples were representative of agricultural soil. Each soil sample was grid sampling of a fixed depth (0-30 cm) within each sampling station using shovel. After removing top vegetation, root, stubble and litter, collected samples and kept in zipper storage bags to avoid contamination and transported to the laboratory. The soil samples were air-dried at room temperature until soil dry then crushed in mortar pestle and passed through a 2 mm, 0.5 mm mesh sieve after that stored in zipper storage bags for laboratory analysis.

3.3 Laboratory analysis

3.3.1 Analysis of soil pH

Soil pH was measured by pH meter in a 1:1 (w/v) soil to deionized water ratio suspension. Weighed 20 g of dry soil and added 20 mL of water in a 100 mL beaker then stirred well with a glass rod. After stir well followed by 30 min of equilibration period and measured the pH of the solution with a well calibrated pH meter (WP).

3.3.2 Analysis of Electrical conductivity

Electrical conductivity (EC) was measured by Electrical conductivity meter in a 1:5 (w/v) soil to deionized water ratio suspension. Weighed 4 g of dry soil and added 20 mL of water in a 100 mL beaker then stirred well with a glass rod. After stir well followed by 30 minutes of equilibration period and measured the EC of the solution with a well calibrated Electrical conductivity meter (Hach Senion156).

3.3.3 Analysis of soil texture

Soil texture was determined particle size by the hydrometer method (Brady and Weil, 1999; Bohn at al., 2001; Tan, 1995). Weigh 50 g of 2 mm dry soil and put it into 250 ml erlenmeyer flask then add 100 ml of Calgon 5% and allowed it to stand overnight. Stir with Hamilton beach for 5 minutes and put it into measuring cylinder after that immersed the hydrometer in the cylinder and add deionized water to 1130 ml of measuring cylinder. Took hydrometer out and stir it for 1 minute. Determined the volume of the hydrometer and temperature at 40 second (R_{40s}, t_{40s}) and 2 hours (R_{2h}, t_{2h}) then calculated sand silt and clay.

3.3.4 Analysis of organic matter

Soil organic matter was determined by Walkley and Black method (Bohn et al., 2001; Tan, 2005). Weighed 0.5 g of 0.5 mm dry soil and put it into 500 ml erlenmeyer flask then added 10 ml of 1N $K_2Cr_2O_7$ and swirled the flask gently then added 20 ml of conc. H_2SO_4 and immediately swirled the flask until the soil and the reagent are mixed. Set aside to cool slowly on an asbestos sheet in a fume cupboard for 30 minutes. Dilute to 200 ml with deionized water then filter it. Added 10 ml of 85% H_3PO_4, 0.2 g of NaF and 5 drops of O-phenanthroline-ferrous complex (Ferroin) indicator then proceed with the 0.5 N of $Fe(NH_4)_2(SO_4)_2$ titration then calculated and % organic matter.

3.3.5 Analysis of cation exchange capacity

Cation exchange capacity (CEC) was determined by ammonium saturation method (Brady and Weil, 1999). Weighed 10 g of 0.5 mm dry soil and added 50 ml of 1 N NH_4OAc then shook it with shaker for 30 minutes. Filtered the soil with suction flask and vacuum pump which the Buchner funnel use filter paper no. 42. Leached the soil with 150-200 ml of NH_4OAc. Washed out the electrolyte with 150-200 ml of 95% Ethyl alcohol then Determined the adsorbed NH_4 by leach with 250 ml of 0.1 N HCl and put it into 500 ml flask. After that took 10% of total solution and put it into digestion tube. Determined the CEC by used Buchi distillation unit.

3.3.6 Analysis of availability micronutrient

Available micronutrients concentration was determined by DTPA extraction (LDD, 2005). Weighed 20 g of 0.5 mm dry soil and put it into 100 ml Erlenmeyer flask then added 40 ml of DTPA. Shook it with shaker for 2 hours. Filtered the soil with filter paper no. 42. After that determined the available micronutrients by using Atomic absorption spectrophotometry (AAS) with specific wavelength for Cu, Fe, Mn and Zn.

3.3.7 Statistical and geostatistical Analysis

Descriptive statistics such as minimum, maximum, mean, standard deviation, Spearman's correlation coefficient and Pearson’s correlation coefficients were conducted to describe available micronutrients, organic matter, organic carbon, pH, EC and CEC. The statistical analysis was run the parameters in the SPSS software. Spatial variability of available micronutrients carried out by an inverse distance weighting (IDW) interpolation technique using Arc GIS software.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Characteristics of soil proportions in study areas

Descriptive statistics such as mean, standard deviation (SD), maximum, minimum, and range were used to explain characteristics of soils. Of the 40 soil samples, two samples were detected to be outliers. They were therefore removed from the burning and non-burning dataset. The analysis was applied based on 38 samples.

4.1.1 Soil texture

Soil texture of burning and non-burning paddy soils represented clayey texture with higher average percentage of clay in burning paddy field (61.55±2.02%) when compare to non-burning paddy field (58.55±1.36%). The color of burning paddy soil is black and very dark gray to black in non-burning paddy soil. The soil texture influences the soils' ability to store water and nutrients. Clayey soils generally contain more organic matter and nutrients than sandy soils. Organic matter in the soil mimics the positive effects of clay. Soils with high clay content increases CEC and thus the ability to hold nutrients. Clay has ability to attract and hold nutrients in the soil and thus fewer nutrients are lost when water drains through clay soils.

4.1.2 pH

pH affects nutrient availability by changing the nutrient form. Micronutrients may become adsorbed or desorbed, precipitated, mineralized, or immobilized at different pH values. The ranges of pH in burning and non-burning paddy soils are 7.0 to 7.6 and 7.1 to 7.6, respectively, implying that soils were neutral to weak alkaline. Calcareous soils contain from 1 to 90 % lime material as calcium carbonates and these sparingly soluble salts cause the soil to have a pH of 8.0 to 8.2 which is not a severe problem for plant growth or agricultural production. Problems are encountered in alkaline soils when sodium occurs or accumulates and forms salts such as sodium bicarbonate and sodium carbonate. These are highly soluble and increase the soil pH above 8 (Hall et al., 2009). Soils with high alkalinity can reduce availability micronutrients, resulting in deficiencies, and they may contain excessive levels of soluble salts or sodium which are harmful to plants. The pH range of 5.5 to 7.5 is considered a balance condition for plants (QLD, 2016), so that essential nutrients can be taken up from the soil through their roots.

4.1.3 Electrical conductivity (EC)

The EC analyzed at 25°C in burning paddy soils ranged between 0.12 and 0.20 dS/m with a mean±SD of 0.56±0.03 dS/m. Non-burning paddy soil salinity varied between 0.11 and 0.22 dS/m, with an average salinity and SD of 0.17±0.03 dS/m. Electrical conductivity is the most common measure of soil salinity and indicative of the ability of an aqueous solution to carry an electric current. The depth of the soil can directly affect its electrical conductivity. Plants are detrimentally affected by excess salts in some soils and by high levels of exchangeable nutrients. Gratten (2002) found a decrease in rice grain yield when salinity in field water was above 1.9 dS/m. Based on the results, these ranges of salinity created no effects on plant growth and crop yields.

4.1.4 Cation exchange capacity (CEC)

The range of CEC in burning paddy soils was 5.67 to 7.46 cmol/kg with a mean±SD of 6.89±0.40 cmol/kg. CEC in non-burning paddy soils was slightly lower with a range of 4.64 to 5.28 cmol/kg with an average 5.03±0.15 cmol/kg. Cation exchange capacity is an expression of the soil's ability to hold and exchange cations. Soils with high CEC are typically high in clay minerals and soil organic matter, which have a lot of negative charges. Soils with high CEC not only hold more nutrients, they are better able to buffer or avoid rapid changes in the soil solution levels of these nutrients. CEC increases with pH, due to variable charge on the organic matter. Clay and humus have high CECs because they are tiny particles with very large surface-to-volume ratio, with many negative sites that can attract cations. However, CEC varies according to the type of clay. It is highest in montmorillonite clay. It is lowest in heavily weathered kaolinite clay and slightly higher in the less weathered illite clay. The low range of cation exchange capacity in Thailand was also reported by Kawaguci and Kyuma's study (1974). They found the cation exchange capacity of Thailand is low in comparison with the other country in tropical Asia, due to sandy soils from the Khorat Plateau.

4.1.5 Organic matter

Organic matter content in burning paddy soils varied widely from 2.35 to 4.59%, a mean±SD of 3.74±0.65%, A narrow range (1.70 to 2.65%) and lower mean±SD (2.28±0.25%) values were found in non-burning paddy soils. Both areas indicated moderate to high contents of OM. Soil organisms use organic matter as food, breaking it down to obtain energy and essential nutrients. Organic matter releases nutrients in a plant-available form upon decomposition. Not of all the nutrients released from organic matter breakdown will be available to plants some is lost from the system and some is taken up by microorganisms to support microbial activity and growth. Organic matter levels are reduced through cropping and can be replenished by adding compost or manure, or crop residues, or green manure. Soil organic matter can be conserved with reduced tillage practices. Organic matter is also added to clay to increase aggregation and thereby improve drainage.

Table 1 Statistical summary of characteristics of soil proportions and available concentrations of Cu, Fe, Mn and Zn between burning and non-burning paddy soils.

Paddy soil	Burning			Non-burning			suitable range
Parameter	min	max	mean	min	max	mean	
pH	7.00	7.60	7.0 to 7.6	7.1	7.6	7.1 to 7.6	Acid: <6.5 Neutral: 6.6 to 7.3 Base: >7.4
EC (ds/m)	0.12	0.20	0.56±0.03	0.11	0.22	0.17±0.03	High: >8 Moderate: 4 to 8 Low: <4
CEC (cmol/kg)	5.67	7.46	6.89±0.40	4.64	5.28	5.03±0.15	High: >25 Moderate: 15 to 25 Low: <15
OM (%)	2.35	4.59	3.74±0.65	1.70	2.65	2.28±0.25	High: >2.5 Moderate: 1.5 to 2.5 Low: <1.5
Clay (%)	57.48	64.56	61.55±2.02	56.20	60.92	58.55±1.36	NA
Cu (ppm)	2.82	7.15	5.74±1.14	2.14	3.84	3.26±0.46	High: >0.2 Low: <0.2
Fe (ppm)	4.90	20.93	12.02±4.41	6.32	10.42	8.51±0.99	High: >4.5 Moderate: 2.5 to 4.5 Low: <2.5
Mn (ppm)	5.80	18.01	11.86±3.61	6.00	9.54	7.18±0.81	High: >1.0 Low: <1.0
Zn (ppm)	0.00	1.20	0.50±0.38	0.00	1.34	0.31±0.38	High: >1.0 Moderate: 0.5 to 1.0 Low: <0.5

Sources: pH (Beck, 1999; Blackemore, 1987), EC (Beck, 1999; Bower and Wilcox, 1965; Jackson, 1658) CEC (Chapman, 1965; Landon, 1991), OM (Allison, 1965), Texture (Brady and Weil, 1999; Bohn et al, 2001; Tan, 1995), Available micronutrients (Viet and Lindsay, 1973)

4.2 Comparison of available concentrations of Cu, Fe, Mn and Zn between burning and non-burning paddy soils.

The content of available micronutrients was formed in the following order: Fe>Mn>Cu>Zn. All micronutrients were significantly greater in burning paddy field than non-burning field (Table 2). The available concentrations of Zn in burning and non-burning paddy soils were not significantly different. The available concentrations of Cu and Mn are significantly different at $p < 0.001$ and available concentrations of Fe are significantly different at $p < 0.01$ in burning as compared to non-burning paddy soils.

Zn deficiency in rice paddy fields occurred in burning and non-burning paddy fields. These results support the common observations that Zn deficiency is a worldwide problem for crop plants in calcareous soils, limiting growth and productivity also found those problems in Thailand (Takrattanasaran et al., 2013). The climatic influence on micronutrient availability in soils which soil pH, climate effects the organic matter level in the soil (Katyal et al., 1982) considered low organic matter cause for generally low available Zn in arid and semiarid soils. Soils of the arid and semiarid regions of Thailand were found more frequently Zn deficient than those in humid and sub-humid zones. Zn deficiency is most pronounced under high yield intensive cultivation systems. The methods of stubble burning and tillage mainly influenced Zn significantly. In the 0-50 mm layer stubble burning decreased the Zn of the ploughed and mechanical weeded plots (Du Preez et al, 2001). Although available micronutrients in soils are generally present in small quantities, post-fire changes could be especially important for plants and lead to deficiencies or to toxicity effects in some soils (García-Marco and González-Prieto, 2008).

Fire impacts on soil properties can be direct or indirect. Direct impact of fire on soil properties is usually short because soils are poor conductor of energy, the heating induced by fire is restricted to the first few centimeters of the soil (Badia et al., 2014). The indirect impacts of fire are related to the ash-bed effects, degree of vegetation recuperation, post-fire weather patterns, topography and post-fire management. Fire management increases the soil available cations (Debano and Conrad, 1978; Trabaud, 1983) due to the accumulation of ashes rich in oxides and carbonates of basic ions (Carballas, 1997; Certini, 2005; Chandler et al., 1983; Kutiel et al., 1990) but it can be lost through wind or water erosion. Removal of ash by erosion can increase the level of micronutrients in waterways. Moreover, microbial population was destroyed completely just after the burning and recolonization occurred after some days (Sharma, 1981). Post-fire management, soil quality and conservation, soil available micronutrients often increased after fire. Low severity fires can have beneficial impacts on soil properties, since the temperatures reached are not high and the loss of nutrients by volatilization and with smoke are reduced. high-severity fires combust a large amount of fuel and have extremely negative impacts on soil. One of the most important impacts is the large reduction in soil cover (Pereira et al., 2014). Low severity fires are less impact to soil physical than high severity fire. High temperatures at the soil surface reduce the quantity of organic materials and induce important transformations in organic matter composition (Merino et al., 2006). In addition, open burning of rice straw after harvesting releases a large amount of air pollutants, which can cause serious effects on the ambient air quality, public health and climate. Rice straw burning can affect the air quality in the area significantly. Smoke from the rice straw burning in Pathumthani is frequently transported toward Bangkok city following the Northeast monsoon during the dry season when the burning is intensive. This may contribute significantly to the already high air pollution in Bangkok in the dry season (Tipayarom et al, 2007).

Table 2 Statistical summary of comparison of available concentrations of Cu, Fe, Mn and Zn between burning and non-burning paddy soils.

Micronutrients	Paddy field	N	Mean	SD	t	p-value
Cu	Burning	19	5.74	1.14	8.73	0.000
	Non-burning	19	3.26	0.46		
Fe	Burning	19	12.02	4.41	3.38	0.003
	Non-burning	19	8.51	0.99		
Mn	Burning	19	11.86	3.61	5.52	0.000
	Non-burning	19	7.18	0.81		
Zn	Burning	19	0.50	0.38	1.58	0.124
	Non-burning	19	0.31	0.38		

4.3 Correlations of micronutrient availability and soil properties.

The available micronutrient of Cu, Fe, Zn in burning paddy soils and Cu, Fe in non-burning paddy soils strong correlation with organic matter could be partly due to organic matter contains a wide range of micronutrients according to its composition. When micronutrients are dissolved in soil solution, in ion or chelating forms they become available for plants. However, the dissolved micronutrients undergo a reaction with compounds such as phosphates (PO_4^{3-}) and carbonates (CO_3^{2-}) to form chemical precipitates or they may interact with clay, other mineral complexes and organic matter resulting in micronutrient unavailability to plants (Yin et al., 2002). Organic matter release micronutrient in the soil solution through weathering and microbial decomposition. Organic material is an important source of micronutrients which constituents carry a negative charge and able to adsorb cations. Micronutrients are frequently present in the soil solution as organic complexes of the total amount in the soil solution this can amount to 50-55% for Mn, 75 to 85% for Zn and 80 to 90% for Cu (McGrath et at., 1988). The divalent Cu ion has a strong affinity to soil organic matter compared with other divalent cations. Increasing organic matter caused Zn to increase in the Mn and Fe oxide fractions at the expense of the Zn in the other fractions. Released Zn may have been occluded in these fractions or been strongly adsorbed (Shuman, 1988). About 70–80% water soluble Zn added to soil was converted to water insoluble forms. Soils which organic matter has been applied or which are naturally high in organic matter are favors the low redox potentials, the organic matter favors the growth and metabolism of anaerobic microorganisms (Pomnamperuma, 1965). Low redox potentials may lead to very high Fe^{2+} concentrations.

Micronutrient cations that would ordinarily precipitate at the pH values found in most soils are maintained in solution through complexation with soluble organics. Many biochemicals synthesized by microorganisms form water-soluble complexes with micronutrient. The available micronutrient of Mn, Fe in burning paddy soil were significantly and negatively correlated with soil pH. This strong correlation of Mn availability increases as soil pH decreases. The most obvious features of the chemistry of Mn in simple aqueous solutions are the stability of the divalent cation Mn^{2+} in acid solution and the greater stability of MnO_2 in alkaline solution and in the presence of

O_2. The increase in pH as result of straw burning is generally attributed to the fact that the remaining ash is dominated by carbonates of several metals (Kumar and Goh, 2000). Numerous researchers reported a low pH with conservational rather than conventional tillage systems.

The capacity of the soil to hold on to cations called the cation exchange capacity (CEC). These cations are held by the negatively charged clay and organic matter particles in the soil through electrostatic forces. Cations such as Zn and Cu are typically present in the soil in low concentration to occupy much of the CEC. The available micronutrient of Cu in non-burning paddy soil and Cu, Fe in burning paddy soil were significantly and positively correlated with cation exchange capacity in non-burning paddy soil. High value of CEC offers a large nutrient reserve. The determination of the cation exchange capacity of clays by exchange with the cationic copper complexes such as $[Cu(en)_2]^{2+}$ and $[Cu(trien)]^{2+}$. The CEC values of the $[Cu(en)_2]^{2+}$ exchange is only obtained when a buffer is added to the equilibrium solution after separation of the clay, because the molar extinction coefficient of this complex depends on the pH of the solution (Ammann et al., 2005). Soil acidity is controlled by the amount of hydrogen (H^+) and aluminum (Al^{3+}) that is either contained or generated by the soil and soil components. Soils with a high CEC have a greater capacity to contain or generate these sources of acidity. The more clay and organic matter available, the greater the ability of a soil to adsorb cations.

Table 3 Statistical summary of the relationship of micronutrient availability and soil properties in burning paddy field

Micronutrients	pH	EC	CEC	OM	Sand	Fine particles
Cu	-0.263	-0.144	0.572*	0.819**	-0.417	0.417
Fe	-0.518*	-0.120	0.474*	0.588**	-0.546*	0.546*
Mn	-0.591**	-0.322	0.426	0.525*	-0.411	0.411
Zn	0.033	0.168	0.382	0.829**	-0.235	0.235

Table 4 Statistical summary of the relationship of micronutrient availability and soil properties in non-burning paddy field

Micronutrients	pH	EC	CEC	OM	Sand	Fine particles
Cu	0.230	-0.186	0.619**	0.761**	0.158	-0.158
Fe	0.502*	-0.374	-0.106	0.497*	0.061	-0.061
Mn	0.083	0.098	0.346	0.309	0.309	-0.309
Zn	0.252	-0.335	-0.562*	0.086	-0.127	0.127

Abbreviations: EC = electrical conductivity, CEC = cation exchange capacity, OM = organic matter, Fine particles = a combination of silt and clay percentage

** Correlation is significant at the 0.01 level (2 tails)

* Correlation is significant at the 0.05 level (2 tails)

4.4 Spatial distribution of soil micronutrient concentration

Inverse distance weighting (IDW) Interpolation was used to obtain the spatial distribution of soil micronutrient concentration maps. In burning paddy soil, the available micronutrients of Fe and Mn showed slightly different patterns of geographical variation, higher values were found in the northern. The distribution pattern of Cu and Zn was distributed throughout the area. Higher values of the micronutrients were recorded in the northern, northwest and southeast part of paddy field. As observed for Fe and Mn, the available micronutrient concentrations tended to be lowest in southern part of paddy field where the soil pH is weak alkaline which confirmed their strong negative association. The distribution patterns between Cu, Fe, Zn in burning, Cu in non-burning paddy soil and organic matter maps confirmed their strong positive association. In non-burning paddy soil, the distribution pattern of available micronutrient of the studied was distributed throughout in the northern part of paddy field. Cu distribution pattern of the studied was recorded higher values in northern part whereas Zn distribution pattern was recorded higher value in southern part of paddy field. In eastern part of paddy field was found higher value of the available Mn distribution pattern and Fe distribution pattern of the studied was recorded higher values in southwest part of paddy field. The distribution patterns of Cu, organic matter and CEC tended to be higher value in the northern part of non-burning paddy field which confirmed their strong positive association.

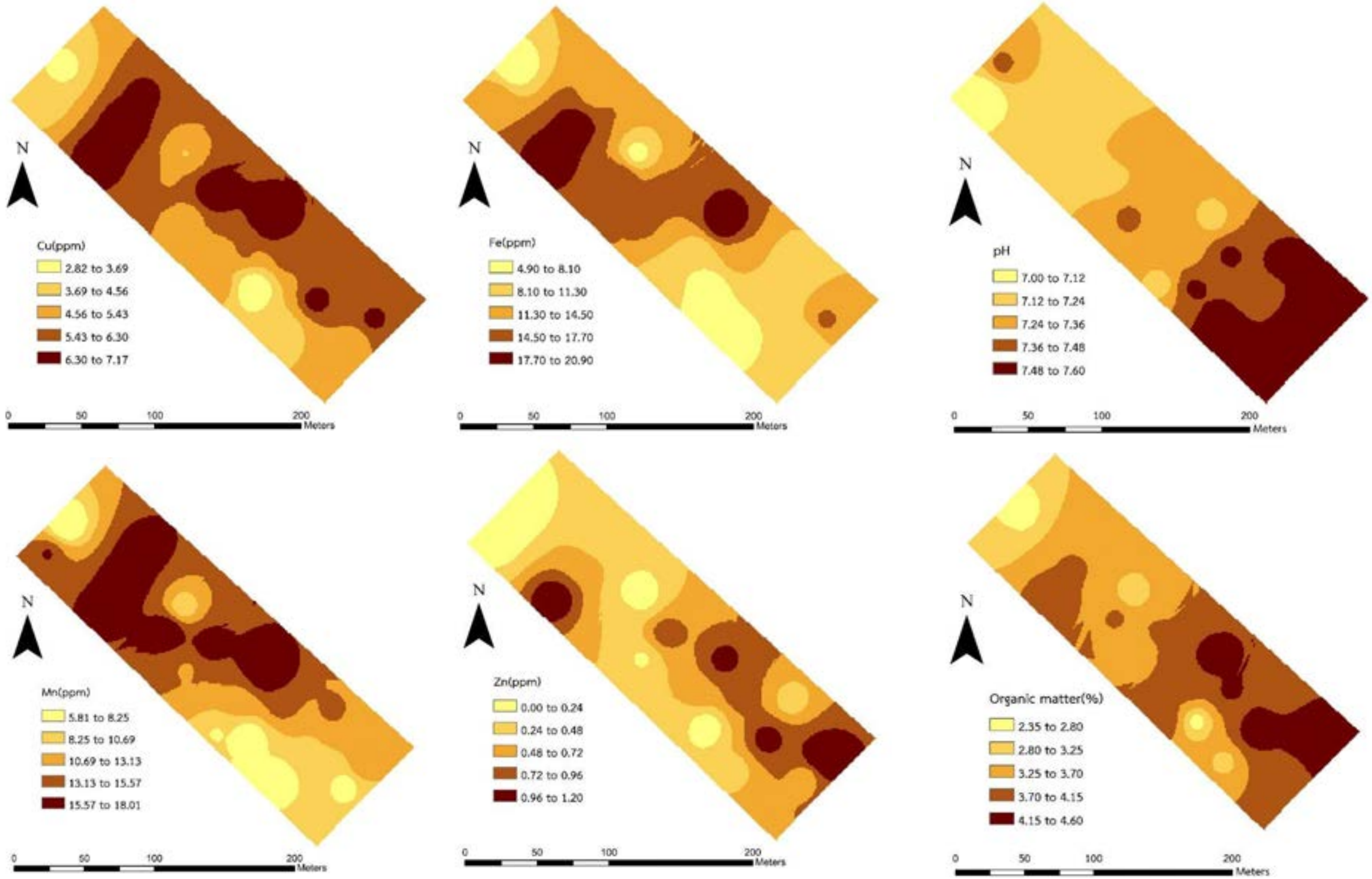

Fig.3 Spatial variability of soil micronutrient concentrations in burning paddy field, Nong Don district, Saraburi.

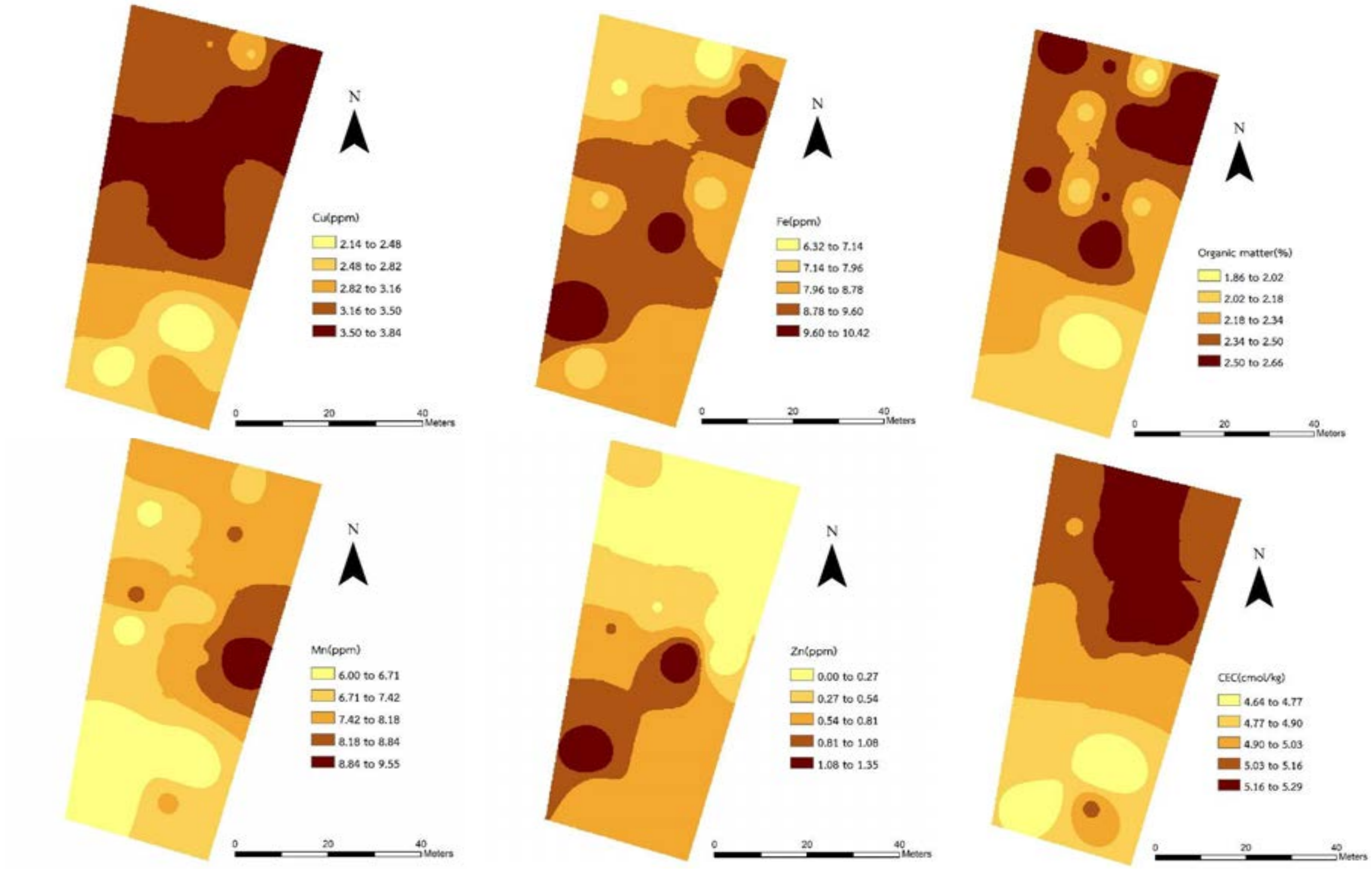

Fig.4 Spatial variability of soil micronutrient concentrations in non-burning paddy field, Phra Phutthabat district, Saraburi.

CHAPTER V

CONCLUSIONS

‘ The available micronutrients measured in soil samples from both sites followed the order: Fe>Mn>Cu>Zn. Higher Cu, Fe, Mn concentrations in the burning paddy field were detected significantly than in non-burning paddy soil. The relationships between organic matter and all micronutrients were moderate (Mn) to strong (Cu, Fe and Zn) in the burning paddy field, whereas OM were moderate (Fe) to strong (Cu) in the non-burning paddy soil. Organic matter constituents carry a negative charge and contain a wide range of micronutrients, micronutrients were then released in the soil solution through weathering and decomposition. In the burning paddy field, Mn was significantly associated with pH and OM whereas Fe was significantly associated with multiple parameters such as pH, CEC, OM, sand and fine particle. High alkalinity and low CEC can reduce availability of micronutrients. However, CEC varies according to the type of clay and organic matter. In the non-burning paddy soil, the relationships between CEC were moderate (Zn) to strong (Cu). Low severity fires may not impact to soil physical. However, open burning in paddy field releases a large amount of air pollutants. The rice paddy fields showed low concentrations of available Zn concentration in general. Application of Zn source materials with pH adjustments or better management strategies can help suppress the Zn deficiency in rice growth.

Recommendations

1.) Application of seed soaking with $ZnSO_4$ solution can be an effective and economical method for improving a Zn deficiency.
2.) The farmer should be ensured that burning is conducted legally and safely, that air pollution does not cause problems or should be formulated and enforced regulations on burning.

References

Adams, S.N., Honeysett, J.L., Tiller, K.G. and Norrish, K. Factors controlling the increase in cobalt in plants following addition of a cobalt fertilizer. Aust. J. Soil Res 7 (1969): 29–42.

Alam, S.M. Effects of iron and manganese on the growth of rice and on the contents of these elements in rice plants. Agronomie, EDP Sciences. 5 (1985): 487-490.

Allison, L.E. Organic Carbon. In Methods of soil analysis, part 2. Amer. Soc. Agron. Madison. Wisconsin, 1965: 1367-1378.

Ammann, L., Bergaya, F., & Lagaly, G. Determination of the cation exchange capacity of clays with copper complexes revisited. Clay Minerals. 40 (2005): 441-453.

Badía, D., Martí, C. Fire and rainfall energy effects on soil erosion and runoff generation in semi-arid forested lands. Arid Land Res. Manag. 22 (2008): 93–108.

Baishya, L., Sarkar, D., Ansari, M., R Singh, K., B Meitei, C., & Prakash, N. Effect of micronutrients, organic manures and lime on bio-fortified rice production in acid soils of Eastern Himalayan region. Ecology, Environment and Conservation. 22 (2016): 199-206.

Barrow, N.J. Mechanisms of Reaction of Zinc with Soil and Soil Components. Dordrecht: Springer Netherlands, 1993: 15-31.

Beck, R. Soil Analysis Handbook of Reference Methods. Soil and Plant Analysis Council, Inc. CRC Press, USA., 1999: 247.

Blakemore, L.C., Searle, P.L., Dalay, B.K. Methods for Chemical Analysis of Soils. NZ Soil Breau Scientific Report 80. Lower Hunt, New Zeland, 1987: 103.

Blume, H.P., Brümmer, G.W., Fleige, H., Horn, R., Kandeler, E., Kögel-Knabner, I., Kretzschmar, R., Stahr, K., Wilke, B.-M. Soil-Plant Relations. Berlin, Heidelberg: Springer Berlin Heidelberg, 2016: 409-484.

Bohn, H.L., McNeal, B.L., O'Connor, G.A. Soil Chemistry. 3rd ed. Canada: John weiley & Sons, 2001.

Bower, C.A., Wilcox, L.V. Soluble salt. In Methods of Soil Analysis, part 2. Black(ed). American Society of Agronomy Inc. USA., 1965: 933-951.

Brady, N.C., Weil, R.R. The Nature and Properties of Soils. 12th ed. New Jersey: Prentice-Hall, 1999.

Carballas, T. Effects of fires on soil quality., Brussels, Belgium: European Commission, 1997.

Certini, G. Effects of fire on properties of forest soils. Oecologia 143 (2005): 1–10.

Chapman, H.D. Cation Exchange Capacity. In Methods of soil analysis, part 2. Amer. Soc. Agron. Madison. Wisconsin, 1965: 891-913.

Chandler, C., Cheney, P., Thomas, P., Trabaud, L., Williams, D. Fire in forestry. New York: Wiley, 1983.

Cosslett, T.L., Cosslett, P.D. Rice Cultivation, Production, and Consumption in Mainland Southeast Asian Countries: Cambodia, Laos, Thailand, and Vietnam. Singapore: Springer Singapore, 2018: 29-53.

Daintith, J., Matin, E. Dictionary of Science. 6th ed. Oxford University Press, 2010: 526.

Debano, L.F., Conrad, C.E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59 (1978): 489-497.

Dou, F., Soriano, J., Tabien, R.E., Chen, K. Soil Texture and Cultivar Effects on Rice (Oryza Sativa, L.) Grain Yield, Yield Components and Water Productivity in Three Water Regimes. 2016.

Du Preez, C.C., Steyn, J.T., Kotze, E. Long-Term Effects of Wheat Residue Management on Some Fertility Indicators of a Semi-Arid Plinthosol. Soil and Tillage Research 63 (December 2001): 25-33.

Everard, M. Rice Paddies. Dordrecht: Springer Netherlands, 2016: 1-4.

Food and agriculture organization(FAO). crop residues and livestock residues. Bioenergy and Food Security Rapid Appraisal. [online]. 2014. Available from : http:// www.fao.org/3/a-bp843e.pdf [2018 October 25]

Food and agriculture organization(FAO). Management of Calcareous Soils. FAO Soils Portal. [Online]. 2018. Available from : http://www.fao.org/soils-portal/soil-management/management-of-some-problem-soils/calcareous-soils/en/ [2018, October 25]

Gafur, A., Koch, C.B., Borggaard, O. Weathering Intensity Controlling Sustainability of Ultisols under Shifting Cultivation in the Chittagong Hill Tracts of Bangladesh. Soil Sci 169 (2004): 663–674.

García-Marco, S., González-Prieto, S. Short- and medium-term effects of fire and fire-fighting chemicals on soil micronutrient availability. The Science of the Total Environment 407 (2008): 297–303.

Gilkes, R.J., McKenzie, R.M. Geochemistry and Mineralogy of Manganese in Soils. Dordrecht: Springer Netherlands, 1988: 23-25.

Grattan, S., Zeng, L., Shannon, M., Roberts, S. Rice is more sensitive to salinity than previously thought. California Agriculture 56 (2002): 189-198.

Gupta, U.C., Wu, K., Liang, S. Micronutrients in Soils, Crops, and Livestock. Earth Science Frontiers 15 (September 2008): 110-25.

Hall, J., Maschmedt, D., Billing, B. The soils of southern South Australia, Department of Water, Land and Biodiversity Conservation. Adelaide,2009.

Hazelton, P., Murphy, B. Soil Properties. CSIRO Publishing, 2011.

Hazelton, P., Murphy, B. Cation Exchange Capacity and Exchangeable Cations. CSIRO Publishing, 2016.

Hazelton, P., Murphy, B. Organic Matter Content of Soils. CSIRO Publishing, 2007.

Hossner, L.R., Yatsu, E., Young, L.M., Warland, J., Stoops, G., Chesworth, W. Micronutrients. Dordrecht: Springer Netherlands, 2008: 466-474.

Huang, Q., Tang, S., Huang, X., Zhang, F., Yi, Q., Li, P., Fu, H. Influence of Rice Cultivation on the Abundance and Fractionation of Fe, Mn, Zn, Cu, and Al in Acid Sulfate Paddy Soils in the Pearl River Delta. Chemical Geology 448 (January 2017): 93-99.

Jackson, M.L. Soil chemical analysis. Prestige-Hall, Inc. New York,1958: 498.

Jeng S.L., Zainuddin, A.M., Sharifah, R.W.A., Haslenda, H. A review on utilisation of biomass from rice industry as a source of renewable energy. Renew. Sust. Energ. Rev. 16 (2012): 3084–3094.

Katyal, J.C., Agarwala, S.C. Micronutrient research in India. Fertilizer News 27 (1982): 66-86.

Kausar, M.A., Chaudhry, F.M., Rashid, A., Latif, A. Plant Alam, and Soil. Micronutrient Availability to Cereals from Calcareous Soils. Plant and Soil 45 (October 1976): 397-410.

Kawaguchi, K., Kyuma, K.. Paddy Soils in Tropical Asia. Southeast Asian Studies. 12 (1974).

Kogel, J.E., Trivedi, N.C., Barker, J.M., Krukowski, S.T. Micronutrients in Fertilizers. Society for Mining, Metallurgy, and Exploration (SME) (2006): 1269-1279.

Kumar, Goh. Crop residues and management practices: effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. Adv. Agron. 68 (2000): 197-319.

Kumar, P., Joshi, L. Pollution Caused by Agricultural Waste Burning and Possible Alternate Uses of Crop Stubble: A Case Study of Punjab. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013.

Kutiel, P., Naveh, Z., Kutiel, H. The effects of a wildfire on soil nutrients and vegetation in an Aleppo pine forest on Mount Carmel, Israel. The Hague: SPB Academic Publishing, 1990.

Land development department (LDD). Handbook of Soil, Water, Fertilizer and Plant. Bangkok: Office of Science for Land Development, 2005.

Landon, J.R. Booker Tropical Soil Manual. Addison Wesley Longman Limited. England, 1991.

Lindsay, W.L. Iron Oxide Solubilization by Organic Matter and Its Effect on Iron Availability. Plant and Soil 130 (January 1991): 27-34.

McGrath, S.P., Sand ers, J.R., Shalaby, M.H. The effect of soil organic matter levels on soil solution concentrations and extractabilities of manganese, zinc and copper. Geoderma 42 (1988): 177-188.

Merino, A., Otero, V., Omil, B., Lastra, B., Piñeiro, V., Gallego, P.P. Application of wood ash compared with fertigation for improving the nutritional status and fruit production of kiwi vines. Journal of Plant Nutrition and Soil Science 169 (2006): 127–133.

Nadim, M., Ullah Awan, I., Baloch, M., Khan, E.A., Naveed, K., Ayaz Khan, M., Labar, N. Effect of micronutrients on growth and yield of wheat. Pakistan Journal of Agricultural Sciences 48(2011): 191-196.

Nayyar, V., Chhibba, I. Effect of Green Manuring on Micronutrient Availability in Rice-wheat Cropping System of Northwest India. (2000)

Nevada climate change portal (NCCP). Electric Conductivity of Soil. Nevada climate change portal. [Online]. Available from: http://sensor.nevada.edu/nccp /Education/Clark%20Activities/Articles/Electric%20Conductivity%20of%20Soil. aspx [2018, October 27]

Pathumthani rice research center, Thailand Ministry of Agriculture and Cooperatives. Rice Production Potential of Saraburi. Bangkok: The argicultural co-operative ferderation of Thailand, 2009.

Pereira, P., Úbeda, X., Martin, D., Mataix-Solera, J., Cerdà, A., Burguet, M. Wildfire effects on extractable elements in ash from a Pinus pinaster forest in Portugal. Hydrol. Process 28 (2014): 3681–3690.

Ponnamperuma, F.N. Dynamic aspects of flooded soils and the nutrient of the rice plant. Baltimore, Maryland: Rice Res. lnst, 1965.

Ponnamperuma, F.N. The chemistry of submerged soils. Adv Agron. 24(1972): 29-96.

Prakongkep, N., Suddhiprakarn, A., Kheoruenromne, I., Smirk, M., Gilkes, R.J. The Geochemistry of Thai Paddy Soils. Geoderma 144 (March 2008): 310-24.

Prasad, M.N. Rice Paddies for Trace Element Cleanup: Bioeconomic Perspectives. Elsevier (2016): 251-269.

Queensland Department of Environment and Heritage Protection. Soil pH. [online]. 2016. Available from :https://www.qld.gov.au/environment/land/management/soil/soil-properties/ph-levels [2019, May 8]

Ross, M. The board basics of your soil's pH. [online]. 2015. Available from : https://www.grainews.ca/2015/11/03/the-broad-basics-of-your-soils-ph-2/ [2019, May 17]

Sahrawat, K.L. Organic matter accumulation in submerged soils. Adv Agron. 532(2004): 169-201.

Schoch, P., Binkley, D. Prescribed burning increased nitrogen availability in a mature loblolly pine stand. Forest Ecology and Management 14 (1986): 13–22.

Setia, R., Marschner, P., Baldock, J., Chittleborough, D., Smith, P., Smith, J. Salinity effects on carbon mineralization in soils of varying texture. Soil Biology and Biochemistry 43 (2011): 1908–1916.

Sharma, G.D. Effect of fire on soil microorganisms in a meghalaya pine forest. Folia Mierobiol 26(1981): 321-327.

Shuman, L. Effect of Organic Matter on the Distribution of Manganese, Copper, Iron, and Zinc in Soil Fractions. Soil Science 146 (1988).

Shukla, K., Anshumali. Soil Micronutrient Pools and Their Transfer to Paddy-Crops in Semi-Arid Agro-Ecosystems, Central India. Soil and Tillage Research 180 (August 2018): 164-74.

Swift, R.S., McLaren, R.G. Micronutrient Adsorption by Soils and Soil Colloids. Dordrecht: Springer Netherlands, 1991: 257-292.

Tan, K.H. Soil Sampling, Prepration and Analysis. New York: Marcel Dekker, 1995.

Tan, K.H. Soil Sampling, Preparation and Analysis. 2nd ed. New York: Marcel Dekker, 2005.

Takrattanasaran, N., Chanchareonsook, J., Johnson, P., Thongpae, S., Sarobol, E. Amelioration of zinc deficiency of corn in calcareous soils of Thailand: zinc sources and application methods. Journal of Plant Nutrition 36 (2013): 1275-1286.

Tipayarom, D., Thi, N., Oanh, N.T. Effects from Open Rice Straw Burning Emission on Air Quality in the Bangkok Metropolitan Region. ScienceAsia 33(2007): 339-345.

Trabaud, L. The effects of different fire regimes on soil nutrients levels in Quercus coccifera garrigue. Berlin: Springer-Verlag, 1983.

Venkatesh, M., Majumdar, B., Kumar, K., Patiram. Status of Micronutrient Cations under Various Land Use Systems of Meghalaya. Journal of the India Society of Soil Science 51 (2003): 60-64.

Viets, F.G. Jr, Lindsay, W.L. Testing soils for zinc, copper, manganese and iron. Soil Science Society of America, Madison, Wisconsin, 1973: 153-172.

Walpola, B.C., Arunakumara, K.K.I.U. (2010). Effect of salt stress on decomposition of organic matter and nitrogen mineralization in animal manure amended soils. Journal of Agricultural Sciences 5 (2010): 9–18.

Yin, Y., Impellitteri, C.A., You, S.J., Allen, H.E. The importance of organic matter distribution and extract soil: solution ratio on the desorption of heavy metals from soils. Sci. Total Environ 287 (2002): 107-119

BIOGRAPHY

Name	Miss Boonyaporn Juethong
Date of birth	30 July 1996
Email	bp.boonyaporn@gmail.com
Phone number	+66818041886
Adess	111/177 Kanchanaphisek Road, Bang Rak Phatthana, Bang Bua Thong, Nonthaburi, Thailand 11110
Education	Bachelor of Environmental Science, Faculty of science, Chulalongkorn University, Bangkok, Thailand