UNIVERSITI PUTRA MALAYSIA

GROWTH PERFORMANCE OF RICE IN ZINC DEFICIT SOILS ADDED WITH ZINC, PHOSPHOROUS AND LIME

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By

SHAHRAM MAHMOUD SOLTANI

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

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DEDICATION

Dedicated to my loving wife, **Shiva** who has always shown me her endless love and passed on to me a passion for life, and **my parentsô** soul who have always believed in the value of education.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for for Doctor of Philosophy

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September 2015

Chairman: Professor Mohamed Hanafi Musa, PhD
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Zinc (Zn) is the most limiting micronutrient that its deficiency is a widespread nutritional disorder of tropical wetland rice. The addition of Zn, lime, and phosphorous (P) influences the amounts of plant-available Zn and rice growth. The present study was undertaken to assess native and applied Zn fractions of six tropical paddy soil series under different amendments (P fertilizer, liming and Zn fertilizer additions), and their effect on the soil Zn status, growth, yield, yield components and quality of rice. The Zn deficient soil series were sampled from the topsoil of Kedah and Kelantan paddy fields for incubation (six), glasshouse (three) and field trials (one). The treatments were combination of three levels of Zn with: (i) three levels of P, (ii) two levels of lime (Experiment 2=Zn×P×lime; experiment 3= Zn×lime; experiment 4=Zn×P and experiment 5=Zn×lime) . Sequential extraction of six soil series for Zn fractions indicated that most of the Zn occurred in the residual fraction (around 70%) and the water soluble plus exchangeable (WE) fraction was less than 5% of the total Zn content. The WE fraction had a highly significant positive correlation (0.73^{**}) with organic bound Zn (Org) and significant positive correlations with soil clay content (0.41^{**}) and CEC (0.48^{**}). The glasshouse trials showed that application of Zn significantly increased the dry matter of shoots, stem, total dry matter and total grains weight. The same parameters also increase when P and lime were added to the soils, but their application decreased the Zn status of the soil and Zn content of plant tissues. The best Zn levels were 5 kg ha^{-1} for Kundur and Tepus , and 10 kg ha^{-1} for Telemong soil series. The same results were found in non-limed and limed soil. The highest grain (GY) and straw yield (SDW) were obtained in TPS at 5 kg Zn ha^{-1} level, which were 56 and 23% more than untreated Zn pots. Also, the maximum increase in GY and SDW were recorded at 10 kg Zn ha^{-1}application with 68 and 25% in KDR, and 63 and 33% for TLM soil series, respectively. The highest total, straw, and grain Zn uptake were 11.46, 4.45 and 1.54 mg pot^{-1} in TPS by 10 kg Zn ha^{-1} application, respectively. The highest Zn increase in grain due to Zn application was obtained in TPS soil series (1.68%), (1.10%) for KDR and 1.43% for TLM in glasshouse trials, whereas the decrease in grain Zn due to lime application was recorded for TPS (31%) and TLM (14%). In field trials, application of lime and Zn increased the rice yield about two-fold (6.84 ton ha^{-1}). Also, the Zn in grain increased 30% in comparison with untreated plots. But in all experiments, lime and P application across the Zn levels reduced not only the roots, leaves, stems, panicles and grains Zn contents, but also the Zn use

efficiency. Therefore, the proper management of P, lime and Zn application in paddy fields of the Zn defeciet soils in the tropic can improve rice growth and its Zn bio-fortification.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PERTUMBUHAN PENGAMALAN BAGI PADDY DI TANAH KURANG ZINK DENGAN PENAMBAHAN ZINC, FOSFORUS DAN KAPUR

Oleh

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Zink (Zn) merupakan mikronutrien yang paling terhad yang mana kekurangannya boleh menganggu keperluan nutrien secara meluas dalam tanaman padi secara tropika. Penambahan unsur Zn, pengapuran dan penggunaan baja P adalah mempengaruhi kandungan Zn yang tersedia pada tanaman dan pertumbuhan padi. Kajian ini dijalankan untuk menilai Zn asal dan kepelbagaian Zn pada 6 jenis siri tanah padi tropika di bawah penambahan pembaik tanah yang berbeza (baja P, pengapuran dan penambahan baja Zn) dan kesannya terhadap status Zn dalam tanah, pertumbuhan, hasil, komponen hasil dan kualiti padi. Tanah kurang Zn telah disampel dari tanah lapisan atas di kawasan tanah padi di Kedah dan Kelantan untuk kajian pengeraman (enam), ujian rumah kaca (tiga), dan kerja lapangan (satu). Rawatannya ialah (i) tiga peringkat P, (ii) tiga peringkat Zn, dan (iii) dua peringkat kapur. Pengekstrakan tanah berjujukan mengukur kandungan Zn berada di dalam pecahan sisa (kira-kira 70%) dan pecahan bertakungan serta larut air (WE) yang mana kurang dari 5% dari jumlah kandungan Zn.Pecahan WE mempunyai kolerasi positif yang tinggi (0.73^{**}) dengan ikatan Zn organik (Org) dan ia juga adalah berkolerasi positif yang tinggi dengan kandungan tanah liat di dalam tanah (0.41^{**}) serta keupayaan pertukaran kation KPK (0.48^{**}). Ujian rumah kaca menunjukkan bahawa penggunaan Zn meningkatkan bahan kering pada pucuk, batang, jumlah bahan kering dan jumlah berat bijirin. Parameter yang sama juga telah meningkat apabila P dan kapur ditambah pada tanah tetapi penggunaannya mengurangkan status Zn dalam dan kandungan Zn pada tisu tanaman. Tahap Zn yang terbaik adalah pada 5 kg ha^{-1} untuk siri Kundur dan siri Tepus, dan 10 kg ha^{-1} untuk siri Telemong. Keputusan yang sama juga diperolehi masing-masing dalam tanah yang tidak dikapur dan tanah yang telah dikapur. Bijirin yang paling banyak (GY) dan hasil jerami (SDW) adalah diperolehi dalam siri TPS pada 5 kg Zn ha^{-1}, yang mana 56 dan 23% lebih tinggi dari plot Zn yang tidak dirawat. Juga, penambahan maksima dalam GY dan SDW telah direkodkan pada tahap 10 kg Zn ha^{-1} dengan 68 dan 25% adalah dalam siri KDR, dan 63 dan 33% untuk siri TLM. Secara keseluruhan kadar pengambilan Zn, jumlah tertinggi bagi jerami dan bijirin adalah masing-masing 11.46, 4.45 dan 1.54 mg pot^{-1} dalam siri TPS dengan penggunaan sebanyak 10 kg Zn ha^{-1}. Peningkatan tertinggi Zn dalam bijirin merujuk kepada penggunaan Zn yang diperolehi dalam siri TPS (1.68%), KDR (1.10%) dan TLM 1.43% untuk ujian rumah kaca. Manakala, kekurangan Zn dalam bijirin merujuk kepada penggunaan kapur yang mana telah direkod pada TPS (31%) dan siri TLM

(14%). Dalam ujian lapangan, penggunaan kapur dan Zn telah meningkatkan hasil padi kira-kira dua kali ganda (6.84 t ha^{-1}). Juga, Zn dalam bijirin telah meningkat sebanyak 30% jika dibandingkan dengan plot yang tidak dirawat. Untuk keseluruhan eksperimen, penggunaan kapur dan baja P menunjukkan penurunan pada tahap Zn bukan sahaja pada akar, daun batang, panikel dan kandungan bijirin, tetapi juga melibatkan penggunaan kecekapan Zn. Oleh itu, pengurusan baja P yang baik, penggunaan kapur dan pengurangan Zn dalam tanah sawah padi tropika boleh meningkatkan tumbesaran padi dan ia juga boleh dijadikan sebagai Zn biofortification.

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I certify that a Thesis Examination Committee has met on 4 September 2015 to conduct the final examination of Shahram Mahmoud Soltani on his thesis entitled "Growth Performance of Rice in Zinc Deficit Soils Added with Zinc, Phosphorous and Lime" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AE	Agronomic efficiency
AF	Availability Factor
Amor	Amorphous sesquioxide bound
APE	Agro-physiological efficiency
AR	Acid Reducible Zn fraction
ARE	Apparent Recovery Efficiency
Ava	Available
CEC	Cation Exchange Capacity
Comb	Combination of soil and lime
CP	Crude Protein
Cry	Crystalline sesquioxide
DF	Degree of freedom
DW1	Dry matter weight at maximum tillering stage
DW2	Dry matter weight flowering stage
DW2	Dry matter weight harvesting stage
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
GPP	Grain per Panicle
GW	Grain Weight
GY	Grain yield
GZn	Grain Zinc
ha	Hectare
IAEA	International Atomic Energy Agency
IMM	Immature grain
KDR	Kundur soil series

LR	Lime Requirement
LRGS	Long-term Research Grant Scheme
MN	Manganese oxide bound Zn
MR	Malaysian Rice
OC	Organic Carbon
Org	Organic bound Zn
PCA	Principal Component Analysis
PE	Physiological Efficiency
PH1	Plant height at maximum tillering stage
PH2	Plant height flowering stage
PH3	Plant height harvesting stage
PL	Panicle length
R^2	R square
RE	Relative Error
Redox	Reduction and Oxidation
Res	Residual Zn
SDW	Straw Dry Matter
SSL	Self–sufficiency level
SUMF	Summation of Factions
TLM	Telemong soil series
TN1	Tiller number at maximum tillering stage
TN2	Tiller number at flowering stage
TN3	Tiller number at harvesting stage
TPS	Tepus soil series
UE	Utilization Efficiency
WE	Water soluble plus exchangeable Zn
WHO	World health Organization

CHAPTER 1

INTRODUCTION

Zinc (Zn) is the most important micronutrient that its deficiency is considered to be a serious widespread nutritional disorder of the world's wetland rice (Neue and Lantin, 1994; Wissuwa *et al.*, 2006). Today, the high yielding new varieties are being grown intensively (Hafeez *et al.*, 2009) and, traditionally low concentration of plant-available Zn in native soil leads to available (Ava) Zn depletion in paddy fields, especially in the tropics.

Zinc plays a fundamental role in various metabolic processes in plants and it is a vital component of a series of functional enzymes, such as dehydrogenases, proteinases, peptidases, phosphohydrolases, carbonic anhydrase and superoxide dismutase. Zinc also contributes to auxin metabolism, preferential accumulation of chlorophyll, protein synthesis and starch metabolism. Therefore, soil Zn deficiency adversely influences the crop growth and development (IRRI, 2005; Bell and Dell, 2008). Consequently, the lack of available Zn results in rice losses close to 40-80% of grain yield (Alloway, 2012).

Zinc availability, solubility and subsequent uptake are adversely affected by a number of soil geochemical factors, including high soil pH, high HCO_3^- concentration, low organic matter content, the high concentration of acidic and basic cations, and high phosphorus (P) availability in an anaerobic soil condition (Dobermann and Fairhurst, 2000).

Soil Zn is present in a number of chemical fractions with varying solubilities (Marschner, 1995). These fractions consist of water soluble Zn, adsorbed on exchange sites (exchangeable), organic matter Zn associations, co-precipitated as secondary mineral structures or fixed with sesquioxide crystals and as a structural component of primary minerals (Shuman, 1985; Shuman, 1998; Wijebandara, 2007). These various Zn pools can replenish available Zn pools for plant uptake at different soil conditions (Almendros *et al.*, 2008). These pools differ in strength (or reversibility) and in their susceptibility to plant uptake, leaching, and extractability. The equilibrium among different pools is influenced by pH, Eh, and concentration of Zn and other cations, particularly Fe and Mn. The readily available Zn forms - water soluble, exchangeable and chelated Zn forms - are in a reversible equilibrium with each other (Viets, 1962). Zinc in soluble, organic complexes and reversible exchange fractions are the most important forms to maintain Zn content sufficiency in lowland rice (Murthy, 1982). Knowledge of Zn fractions distribution- indicator of Zn bioavailability between soil solid and solution phases is basic to the understanding of the soil Zn chemistry, and thereby Zn management in soils.

In Malaysia, most of the paddy fields are well established with irrigation systems, double cropping and cultivation of high yielding rice varieties (Ho *et al.*, 2008). Nearly all soils in Malaysia are classified into three soil orders: Oxisols, Ultisols (72% of Malaysian soil orders) and Entisols (Paramananthan, 2000). They are characterized by an extremely leached condition, almost low pH (4-5), high Al activity in the soil solution and low basic cations content (Ca and/or Mg deficiency), which are major factors that affect the crop production and reduce yields in these soils (Shamshuddin and Kapok, 2010; Shamshuddin and Anda, 2012; Shamshuddin *et al.*, 2013). The common pH ranges in the un-limed soils of agricultural paddy fields are lower than 5.

Also, much attention is needed to cope with, improve and optimize Zn deficiency status in rice crop in flooded soil conditions to increase yield and Zn content in grain through addition of various amendments. A markedly higher incidence of Zn deficiencies was found in rice crops due to intensive cropping, loss of fertile topsoil and micronutrients through leaching in tropical soils (Somani, 2008) with high rainfall and temperature, and low trace element concentration in parent materials (Liew *et al.*, 2010). But, it seems that the development of knowledge of achieving balance nutrient status based on soil and plant continuum for sustainable crop production is fundamental and continuously needed.

Furthermore, with respect to the vitality of the increasing rice yields, Zn bio-fortification or the increase of the bio-available Zn content in edible parts of agricultural crops is another immediate goal to improve nutritional quality of crops to control human malnutrition disorders (Hirschi, 2008; Mayer *et al.*, 2008). The widespread Zn deficiency disorders affect around 25% of the world's population (Maret and Sandstead, 2006). Zinc plays a key role in human and animal life cycle, such as human physical growth and development, functioning of the immune, nerve and reproductive systems as well as maturity and health development (Hotz and Brown, 2004).

In spite of the great impact of amendment additions on crop yield and quality, the effect of these methods varies with rice varieties, soil types, crop genotypes, different cropping systems. Thus, further research is needed to explore and integrate all practical solutions to increase crop yield and quality of rice grains. In order to fulfil the research gap in the literature, this study examines the interaction of P, lime and Zn on soil and plant Zn status, rice growth and Zn bio-fortification. To complete this study, there are five distinct hypotheses that need to be accomplished. The hypotheses are:

Hypothesis 1: Increased yield and yield components, Zn uptake and grain quality by MR219 from low Zn soil is the result of more efficient Zn fertilizer application,

Hypothesis 2: Increased yield and yield components, Zn uptake and grain quality by MR219 from low Zn soil is the result of the more efficient soil condition by liming (suitable pH),

Hypothesis 3: Increased yield and yield components, Zn uptake and grain quality by MR219 from low Zn soil is the result of more efficient nutrient antagonistic system (P and Zn relation), Hypothesis 4: Increased yield and yield components, Zn uptake and grain quality by MR219 from low Zn soil is the result of the Zn fractions status of paddy soil, and

Hypothesis 5: Increased yield and yield components, Zn uptake and grain quality by MR219 from low Zn soil is the result of Zn and lime interaction.

1.1 Objectives of the Study

To overcome Zn deficiency constraints and to achieve the hypotheses, the objectives of this research are as follows:

1. To quantify native soil Zn fractionation of six tropical paddy soil series and their relationships with soil properties
2. To characterize Zn fractionation of six tropical paddy soil series under different amendments addition (P fertilizer, liming and Zn fertilizer application)
3. To determine the P and Zn interactions following the addition of sufficient Zn and P fertilizer on yield, yield components of rice, soil Zn status and partitioning at different rice growth stages
4. To determine the relationship between liming (pH management), and Zn application on yield, yield components of rice and Zn status under field condition
5. To quantify effects of soil amendment application on rice quality and its bio-fortification.

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