FIELD EVALUATION OF COPPER AND ZINC-COATED UREA ON YIELD AND NITROGEN UPTAKE OF RICE

By

NUR FAIZATULAKMA BT MOHAMED SAZALI

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

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DEDICATION

For my beloved parents,

Robiaidah bt Alang Pin

and

Mohamed Sazali bin Haron

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Masters of Science

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Chair : Mohd Khanif bin Yusop, PhD
Faculty : Agriculture

The current self-sufficiency level for rice in Malaysia is about 71.4% and the average yield of rice in Malaysia is 3.77 t/ha. Zinc and copper are essential micronutrients for the growth of rice due to their role in plant metabolism and physiological processes and deficiency can greatly reduce rice yield. Urea [$(CO(NH_2)_2$] is the most common granular N fertilizer in rice production worldwide but the efficiency of N from added urea in most paddy fields is usually low. Coating the urea granules with polymer or other binding materials seems effective in reducing urea volatilization and leaching. In order to reduce N loss and improve micronutrient status of paddy soils, addition of Zn and Cu-based fertilizers during rice cultivation is essential.The field trial were conducted for 2 seasons consecutively in KADA site in Melur, Kelantan. Rice cultivar, MR219 was used in the experiment for both seasons. While the third season was conducted in MADA site in Tunjang, Kedah using rice cultivar of MR220. The field experiment was designed as a randomized complete block. The treatments consisted of a control and six different types of copper and zinc coated fertilizer combinations namely: 1) urea (control), 2) copper coated urea, 3) copper + urea, 4) zinc coated urea, 5) zinc + urea, 6) copper and zinc coated urea, 7) copper + zinc + urea. Nitrogen was applied as urea (120 kg/ha), while P and K were applied as TSP and MOP with 50 kg of P_2O_5 and K_2O. The paddy was harvested to measure grain yield and the yield components (panicle length, 1000- grain weight, filled and unfilled grain). The plant tissue was analysed for Total N and Cu and Zn using the Kjedahl method and dry ashing method respectively. The soil samples from post-harvested were collected and were analysed for Total N using Kjedahl method, while the concentration of Cu and Zn was determined using dilute double acid method. The data collected were analysed using ANOVA (SAS 9.3), and LSD ($P<0.05$) was used to test the difference among treatments. The result from all three field experiments

showed that application of urea coated fertilizer improved plant growth parameter and nutrient uptake (N, Cu and Zn) in grain over other treatment combinations. However, the addition of Cu and Zn without coated showed no positive effect to the plant growth and yield. Increased in N uptake in plant is due to reduction of N loss by urea inhibitor (Cu and Zn). Nevertheless, coating Cu and Zn to urea managed to avoid them from leaching. Application of Cu and Zn coated urea in season one produced the highest rice yield whereas for seasons two and three, the maximum rice yield was obtained from treatment Zn coated urea. There was large difference of yield between the three season due to two reasons. The first one was due to the different types of soil and the second, was due to the effect of drought. In MADA the soil is made of marine alluvium parent material whereas in KADA the soil is made up from riverine alluvium parent material. In lowland paddy field, water is essential element to maintain good growth. But due to drought, yield in season one is very much reduced compared to season two.

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

KAJIAN LAPANGAN BAGI PENGGUNAAN BAJA KUPRUM DAN ZINC SALUT UREA TERHADAP HASIL PADI DAN AMBILAN BAGI NITROGEN OLEH POKOK

Oleh

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Kadar sara diri bagi pengeluaran padi di Malaysia adalah sebanyak 71.4% dengan purata hasil padi sebanyak 3.77 t/ha. Kuprum dan Zinc adalah mikronutrien yang penting bagi pertumbuhan pokok padi kerana mereka mempunyai peranan yang penting didalam proses fisiologi dan metabolisma tumbuhan. Oleh itu, kekurangan Ku dan Zn boleh menyebabkan pengurangan hasil padi. Urea [$(CO(NH_2)_2$] adalah baja nitrogen yang digunakan secara meluas dalam industri padi, tetapi mempunyai tahap efisiensi yang rendah. Pelbagai cara telah dilakukan untuk memperbaiki tahap efisiensi urea. Antaranya adalah dengan menyalut urea dengan bahan polimer. Cara ini telah berjaya mengurangkan pemeruapan dan larut lesap urea. Selain menggunakan bahan polimer, Ku dan Zn juga boleh digunakan untuk mengurangkan kehilangan N selain dapat menambahbaik status mikronutrien di tanah sawah.Kajian lapangan telah dijalankan sebanyak 2 musim di Melur, Kelantan (KADA) dan satu musim lagi di Tunjang, Kedah (MADA). Varieti padi yang berbeza telah digunakan di kedua-dua lokasi. Bagi kajian di KADA varieti jenis MR219 telah digunakan. Manakala bagi kajian di MADA, varieti jenis MR220 digunakan. Terdapat 7 jenis rawatan yang digunakan dengan satu plot kawalan dan 6 jenis campuran baja digunakan iaitu: 1) urea (kawalan), 2) kuprum salut urea, 3) kuprum dan urea, 4) zinc salut urea, 5) zinc dan urea, 6) kuprum dan zink salut urea, 7) kuprum, zink dan urea. Baja nitrogen ditambah didalam bentuk baja urea sebanyak 120 kg/ha. Selain itu,baja P dan K pula ditambah dalam bentuk baja TSP dan MOP sebanyak 50 kg P_2O_5 dan 50 kg K_2O. Pengukuran hasil dan komponen pokok padi dilakukan semasa akhir musim ketika pokok dituai bagi menentukan kualiti padi. Pokok tuaian dan sampel tanah akan dikeringkan sebelum di analisis bagi mendapatkan jumlah nitrogen, kuprum dan zink. Data yang diperolehi akan dianalisis dengan menggunakan ANOVA (SAS 9.3). Rawatan akan diuji dengan menggunakan LSD pada paras keertian 5%. Data yang diperolehi dari ketiga-tiga musim

menunjukkan penggunaan baja salutan urea berjaya menambahbaik parameter pertumbuhan pokok dan juga pengambilan nutrien dari tanah (nitrogen, kuprum dan zink) berbanding dengan rawatan lain. Peningkatan ambilan nutrien N di dalam pokok adalah disebabkan oleh pengurangan kehilangan baja N dari urea. Selain itu, salutan Ku dan Zn pada urea juga berjaya mengelakkan Ku dan Zn dari larut lesap. Manakala penggunaan baja kuprum dan zink tanpa salutan menunjukkan tiada kesan positif terhadap hasil padi. Di musim yang pertama, rawatan kuprum dan zink salut urea telah memberikan hasil padi yang tertinggi. Manakala di musim kedua dan ketiga, rawatan zink salut urea pula memberikan hasil padi yang tertinggi. Berdasarkan data, terdapat jurang yang besar diantara hasil padi bagi ketiga-tiga musim. Terdapat beberapa faktor yang mempengaruhi perkara ini iaitu jenis tanah yang berbeza dan juga musim kemarau. Tanah di KADA terbentuk dari tanah mendakan sungai manakala di MADA pula terbentuk dari tanah mendakan laut. Hasil padi yang sangat rendah ketika musim pertama adalah disebabkan oleh kemarau yang melanda semasa ujikaji dijalankan. Secara keseluruhan, berdasarkan data yang diperolehi, rawatan zink salut urea memberikan hasil padi yang tinggi dan berjaya menambahbaik komponen pokok.

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

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
Cu	Copper
KADA	Kemubu Agriculture Development Authority
N	Nitrogen
MADA	Muda Agriculture Development Authority
Zn	Zinc

CHAPTER 1

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food for nearly more than half of the world's population. It provides more than 21% of the calorific needs of the world population and up to 76% of the calorific intake of the population in the South East Asian region (Fitzgerald et al., 2009). Global rice consumption particularly in Asia and Africa remains strong mainly due to population and economic growth conditions of countries in those regions. Although Southeast Asia remains the leading source of world rice exports, the production growth rate in the region is projected to slow down over the next decade (Baldwin *et al*., 2011), thus raising food security concerns globally (Parker, 2011).

Rice is a staple food in Malaysia. The current self-sufficiency level for rice production is about 71.4% (Chamhuri *et al.,* 2014). According to statistics, the average yield of rice in Malaysia between 2009 and 2011 was about 3.77 t/ha, which is lower than the global average of almost 4.4 tons per ha in 2011/12 (Baldwin *et al*., 2012). To meet its consumption needs, Malaysia imports rice from countries such as Vietnam, Thailand and Pakistan.

In line with the national agricultural policy, more concerted efforts are therefore needed to meet the targeted production sufficiency level for rice. Whereas Malaysian rice farmers routinely apply macronutrients-based fertilizers such as nitrogen (N), phosphorus (P) and potassium (K). In current situation, nitrogen is the major limiting factor in rice production, where it is reported that rice requires 1 kg of nitrogen to produce 15-20 kg of grain. In order to accommodate rapidly increasing populations, higher yield is needed. Therefore, additional N must be applied (Ladha, *et al*.,2003). Celine *et a.l,*(2010) stated that 85-90 million tonnes of nitrogen fertilizer were added to the soil annually to provide the demand for plant growth and urea [$(CO(NH_2)_2$] is the most common granular N fertilizer in rice production worldwide (Fageria, 2009) and it happened to have low recovery efficiency in most paddy fields.

It also appears that application of micronutrients such as zinc (Zn), copper (Cu), manganese (Mn) and boron (B) is not a usual practice (Zulkefli *et al*., 2004). The occurrence of micronutrient deficiencies is exacerbated by factors such as intensive cropping, loss of fertile top soils and nutrients through leaching and surface runoff (Somani, 2008). Micronutrients deficiency in soil has been reported to greatly affect rice production in the main granary areas in Malaysia (Zulkefli *et al*., 2004).

Increases in crop yields from the application of micronutrients have been reported in many parts of the world (Fageria *et al*., 2002). Zinc and copper are essential micronutrients for the growth of rice due to their role in plant metabolism and physiological processes (Rehman *et al*., 2012; Yruela, 2005) and deficiency can greatly reduce rice yields (Hafeez *et al*., 2013).

Zinc deficiency is considered the most widespread micronutrient disorder in rice field (Fageria *et al*., 2002; Dobermann and Fairhurst, 2000), where it is dominant in temperate and tropical climate (Shivay *et al*., 2008). On top of that, in particularly high pH soil, zinc is common to be deficient (Nasima *et al*., 2011). While Hafeez (*et al*., 2013) stated that almost all crops and calcareous, sandy soils, peat soils and soils with high phosphorus and silicon are expected to be deficient. Cakmak(1999) stated that 30% soils in the world exhibit zinc deficiency to different level. While in submerged and flooded soil showed that decreasing availability of zinc because of the change in pH value and the formation of insoluble zinc compound. (Hafeez *et al*., 2013). Thus, almost all crops give a positive respond to application of zinc.

The sufficiency range for zinc in leaf is 15 to 50 ppm in the dry matter of mature plants to suffice the plant growth and yield. Shortage of zinc in rice will affect several biochemical processes in the rice plant, such as cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation and membrane integrity (Alloway, 2008). Thus, it will cause the plant to be stunted in growth, decreasing number of tillers, chlorosis and smaller leaves, increasing crop maturity period, spikelet sterility and inferior quality of harvested products (Hafeez *et al*.,2013). The plant will also show brown blotches and streaks that may fuse to entirely cover older leaves and in severe cases the plants may die.

Copper is an essential element for all crops, and its influence both carbohydrate and nitrogen metabolism in plants (Nasima *et al*., 2011). Insufficiency of copper in a plant will contribute to the development of specific deficiency symptoms, most of which effect young leaves and reproductive organs. On top of that, it will also affect reduction in pollen viability and increase in spikelet sterility and many unfilled grains (Dobermann and Fairhurst., 2000). Wu *et al*., (2010) also stated that copper deficiency can cause grain sterility that may lead to formation of unfilled grains thus reducing rice production. Some of the symptoms of copper deficiency is development of chlorotic streaks on either side of the midrib of leaf, dark brown necrotic lesions on leaf tips and reduced tillering.

It was reported that copper concentrations in a plant, needs to be maintained. The average content of copper in plant tissue is 10 µg g^{-1} dry weight (Yruela, 2005). Copper availability decreases in soil solutions due to adsorption of copper in soil exchange complexes, as well as due to chemical to chemical fixation as sulfides. Soil copper availability depends on soil pH; it is lower in the alkaline range and higher in the acidic range. (Nasima *et al*., 2011).

Though both zinc and copper fertilization are important, they are needed in a very small amount. The main problem is to apply the fertilizer uniformly to a wide area and these can be solved by coating them to urea because it exists in a larger size and needed in large amount. By coating them to urea, it can enhance the spreading of micronutrient for better uniformity.

Coating the urea granules with polymer or other binding materials seems effective in reducing urea volatilization and leaching. In order to reduce N loss and improve micronutrient status of paddy soils, addition of zinc and copper-based fertilizers during rice cultivation is essential. Data related to the effect of zinc and copper coated urea on lowland rice grown on Malaysian Oxisols is limited. The present study was therefore conducted to address this knowledge gap.

The objectives of this study were;

1) To determine the effect of copper and zinc coated urea on the growth and yield of rice in the field
2) To determine effect of copper and zinc coated urea on zinc and copper uptake in plant tissue
3) To determine the effect of copper and zinc coated urea on nitrogen uptake in rice tissue

REFERENCES

Ali H., Hasnain Z., Shahzad A.N., Sarwar N., Qureshi M.K., Khaliq S., Qayyum M.F. 2014. Nitrogen and Zn interaction improves yield and quality of submerged basmathi rice (*Oryza sativa* L.). Not. Bot. Horti Agrobo. 42(2):372-379

Alias I, O. Othman, H. Mohamad, A. Saad, H. Habibuddin, A.B. Abd Rahman, S. Azlan. 2005. Varieti Padi Baru MR220. Buletin Teknol. Tanaman. 2. pp:7-13

Agarwala SC. Sharma PN. Chatterjee C. Sharma CP. 1980. Copper deficiency-induced changes in wheat anther. Proceeding of the National Indian Science Academy. Part B. Biological Science. India. 46(2):172-176

Akram H.M., Ali A., Sattar A., Rehman H.S.U., Bibi A. 2013. Impact of water deficit stress on various physiological and agronomic traits of thress basmati rice (*Oryza sativa L*.) cultivars. The Journal of Animal and Plant Sciences. 23(5):1415-1423

Alloway BJ, 2008. Zinc in plant nutrition In Zinc in soils and crop nutrition. Second ed. (pp.30-34). Belgium and France. IZA and IFA.

Anan P., Arunee P., Jiraporn B. 2014. Drought impact on rice production and farmers' adaptation strategies in Northeast Thailand. IJERD. 5(1):45-52

Antoniadis V., Robinson J.S., Alloway B.J. 2008. Effect of short-term pH fluctuation on cadmium, nickel, lead and zinc availablity to rye grass in sewage sludge-amended field. Chemosphere. 71:759-764

Baldwin, K., Childs, N., Dyck, J. and Hansen, J. 2011. Southeast Asia’s Rice Surplus. A Report from the Economic Research Service. RCS-12l-01, United States Department of Agriculture.

Bernard Knezek. 1997. Copper. Michigan State University (MSU). Available from https://msu.edu/course/css/853/Copper.html . 6 Feb 2017

Bost M., Houdart S., Oberli M., Kalonji E., Huneau J-F., Margaritis I., 2016. Dietary copper and human health: Current evidence and unresolved issues. Journal of Trace Elements in Medicine and Biology. 35:107-115

Brown M.T., 1986. The effect of zinc germination, survival and growth of *Betula* seed. Enviromental Pollution (Series A) 41:53-61

Buresh RJ, Ramesh KR, Chris CK. 2008. Nitrogen transformations in submerged soils. In: Scheper, JS., Raun WR., (Eds.),Nitrogen in agricultural systems. Agronomy Monograph 49, American Society of Agronomy, Madison, WI, USA. pp. 401-436

Cakmak I, Kalayci M, Ekiz H, Braun H J, Kilinc Y and Yilmaz A.(1999) Zinc deficiency as a practical problem in plant ad human nutrition in Turkey: Field Crops Res. 60:175-188.

Cakmak I., Marschner H. 1988. Increase in membrane permeability and exudation in roots of zinc deficint plants. J. of Plant Physiology. 132(3):356-361

Cakmak I., Marschner H., Bangerth F. 1989. Effect of Zn nutritional status on growth, protein metabolism and levels of indole-3-acetic acid and other phytohormone in bean (*Phaseolous vulgaris* L.). J. Exp. Bot. 40(212):405-412

Celine M D, Francoise D V, Julie D, Fabien C, Laurel G, Akira S.(2010) Nitrogen uptake, assimilation and remobilization in plants: challenges for sustainable andproductive agriculture. Annals of Botany. 105: 1141-11757.

Chaudry F.M., Sharif M. Latif A. Qureshi R.H., 1973. Zinc-copper antagonism in the nutrition of rice (Oryza sativa L.). Plant and Soil. 38 pp:573-580

Chamhuri S, Diana MI, Yasar M, Golam M., 2014. Issues and challenges facing rice production and food security in the granary areas in the East Coast Economic Region (ECER), Malaysia. Research J of Applied Sci, Engineering and Technology. 7(4):711-722

Cruz RT. O'Toole JC. 1984. Response of dryland rice to an irrigation gradient at flowering stage. Agron J. 76(2):178-183

David R.H., Anne M.S., 2013. Plant growth process: Transpiration, photosynthesis, and respiration. Uni. Nebraska, Lincoln Extension

De Datta SK. 1981. Priciples and practices of rice production. New York:Wiley.

De Datta S K.(1986) Improving nitrogen fertilizer efficiency in lowland rice in tropical asia. Fertilizer Research. 9: 171-186.

Dell, B. 1981. Male sterility and outer wall structure in copper dficint plants. Ann. Bot. 48. 599-608

Dobermann A., Fairhust T. 2000. Rice: Nutirent disorders & nutrient management. Handbook series. Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute.

Dutta D., Mandal B., Mandal L.N., 1989. Decrease in availability of zinc and copper in acid to near neutral soils of submergence. Soil Science. 147(3):187-195

Eriksen A.B. and Kjeldby M. 1987. A comparative study of urea hydrolysis rate and ammonia volatilization from urea and urea calcium nitrate. Fertilizer Research.11:9-24

Fageria, N. K. 2009. The use of nutrients in crop plants. Boca Raton, FL: CRC Press.

Fageria, N. K. 2007. Yield physiology of rice. J. of Plant Nutrition. 30(6): 843-879

Fageria N.K., Baligar V.C., Clark R.B. 2002. Micronutrients in crop production. Adv. Agron. 77:185-268

Fageria N.K., N.A. Slaton and V.C. Baligarc. 2003. Nutrient management for improving lowland rice productivity and sustainability. Advances in Agronomy.Vol. 80. pp. 63-152

Farooq M., Wahid A., Kobayashi N., Fujita D., Basra S.M.A 2009. Plant drought stress: effects, mechanisms and management. Agron. Sustain Dev. 29:185-212

Fitzgerald M.A., Mc Couch S.R., Hall R.D. 2009. Not just a grain of rice: The quest of quality. Trends Plant Sci. 14:133-139

Fontes, R.F.L. and Cox, F.R. 1995. Effects of sulphur supply on soybean plants exposed to zinc toxicity. Journal of Plant nutrtition.18:1893-1906

Garg B.K. 2003. Nutrient uptake and management under drought: nutrient moisture interaction, Curr. Agric. 27:1-8

Gioacchini P., Anna N, Claudio M. 2002. Influence of urease and nitrification inhibitors on N losses from soils fertilized with urea. Biol Fertil Soils. 36:129-135

Graham R.D. 1975. Male sterility in wheat plants deficient copper. Nature (London) 254:514-515

Gilmar R.N., Roberta C. N., Luis R.F.,Michel A.C. 2007. Copper concentration of vineyard soils as a function of pH variation and addition of poultry litter. Brazilian Arc of Biol and Tech. vol 50 n.6: 941-948.

Glossary of Soil Science Term. 2008. Soil Science of America. Available from https://www.soils.org/publications/soils-glossary#, 6 Feb 2107

Hadi M. A. B., Nasima J., Arifin A. Hazandy A.H., Ashadie M.K., 2013. Elevation and variability of acidic sandy soil pH: amended with conditioner, activator, organic and inorganic fertilizers. African J. of Agri. 8(29):4020-4024

Haldar M and Mandal L N. 1979. Influence insoil moisture regimes and organic matter application on the extractable Zn and Cu content in rice soil. Plant and Soil. 53:203-213

Hafeez, B., Khanif, Y.M., Saleem, M. 2013. Role of zinc in plant nutrition - a review. American Journal of Exp. Agriculture. 3(2): 374-391.

Harmens, H., Gusmao, N.G.G.P.B., Den Hartog, P.R., Verkeij, J.A.C., and Ernst, W.H.O. 1993. Uptake and transport of Zinc in zinc-sensitive and zinc-tolerant *Silene vulgaris*. Journal of Plant Physiology. 141:309-315.

Huang C., Yang W., Duan L., Jiang N., Chen G., Xiong L., 2013., Rice panicle length measuring system based on dual camera imaging. Com. and Electronics in Agri., 98:158-165

Hwang H. Zhong G. Shi G. Pan F. 2011. Toxicity of Cu, Pb, and Zn on seed germination and young seedlings of wheat (*Triticum aestivum* L.).

Imtiaz M., Alloway B.J., Shah K.H., Siddiqui S.H., Memon M.Y., Aslam M., Khan P. 2003. Zinc nutrtion of wheat II: Interaction of zinc with other trace elements. Asian J. of Plant Science. 2(2):156-160

James DW. 2010. Fertilizer fact sheet - Urea: A low cost nitrogen fertilizer with special management requirements. US: Utah State University. Available from https://www.researchgate.net/file.PostFileLoader.html?id=57f6083fb0366d361750cf91&assetKey=AS%3A414105107222529%401475741759855. 6 Feb 2017

Jay P.V., Vimal S., Janardan Y., 2011. Effect of copper sulphate on seed germination, plant growth and peroxidase activity of mung bean (*Vigna radiata*). International Journal of Botany. 7(2)200-204

Jiakuan Xu, Yang L., Wang Z., Dong G., Huang J., Wang Y. 2006.Toxicity of copper on rice growth and accumulation of copper in rice grain in copper contaminated soil. Chemosphere. 62.602–607

Jack F. Loneragan , Michael J. Webb. 1993**.** Interactions between zinc and other nutrients affecting the growth of plants.

Jones C, Olsen-Rutz K, Dinkins C P. 2011. Nutrient uptake timing by crops. Montana, USA: Montana State University.

Josko O., Sustar N. 2011. Copper and zinc. biological role and significance of copper/zinc imbalance. J.Clinical Toxicology. 3(1):1-18

Kamarudin A., Toshiaki T. 1991. Effect of micronutrient application on the growth andoccurence of sterility in barley and rice in a Malaysian deep peat soil. Soil Science and Plant Nutrition. 37(4):715-724

Kausar M.A., Chaudry F.M., Rashid A., Latif A., Alam S.A. 1976. Micronutrient availability to cereals from calcareous soils I. Comparative Zn and Cu deficiency and their mutual interaction in rice and wheat. Plant and Soil. 45(2):397-410

Kiekens, L. 1995. Zinc in B.J. Alloway (Ed.), Heavy metals in soils(2nd ed., pp.284-305). London: Blackie Academic and Professional

Kirk G. 2004. The biogeochemistry of submerged soils. John Wiley & Sons, New York, USA

Ladha J.K., Pathak H., Agnes TP., Dawe D., Gupta K.R.(2003). Productivity trends in intensive rice- wheat cropping system in asia. ASA Special Publication 65. p; 45-76

Lambers H., Chapin F.S., Pons T.L. 2008. Photosynthesis. Plant physiological ecology. 25:11-99

Lata S.B.U. 2012. Urease inhibitors: A review. Indian Journal of Biotechnology. 11:381-388

Li B. Y., Zhou D. M., Cang L., Zhang H. L., Fan X. H., Qin S. W., 2007. Soil micronutrient availability to crops as affected by long-term inorganic and organic fertilizer applications. Soil and Tillage Research. 96:166-173.

Ljung K. 2013. Auxin metabolism and homeostasis during plant development. Development. 140:943-950

Llyod A.B., Jane Shaeffe M., 1973. Urease activity in soil. Plant and soil. 39:71-80

Mahendra S., Singh S.P. 1981. Effect of nitrogen and zinc on the yield of submerged rice and uptake of N and Zn on unlimed and limed soils. Plant and soil. 62:183-192.

Majid J.M., Hosein H.S., Ghorban N., Yaghoub S.M S.,Ataolah S.S. 2012. The effect of zinc, boron and copper foliar application, on yield and yield components in wheat (*Triticum aesttivum*) Ann. Bio. Research. 3(8):3875-3884

Maksymiec W. 1997. Effect of Copper on cellular processes in higher plants. Photosynthetica. 34(3): 321-342

Maria L.S.S., Godofredo C.V., Anderson R.T. 2014. Heavy metal toxicity in rice and soybean plants cultivated in contaminated soil. Rev. Ceres, Vicosa. 61(2):284-254.

Marschner H. 1995. Functions of mineral nutrients: micronutrients. Chapter 9 in Mineral nutrition of higher plants (2 ed). Academic Press. 313-404

Murayama. N.(1979) The importance of nitrogen for rice production. Nitrogen and rice symposium proceedings. pp. 5-23

Muaz H., Khanif MY, Radziah O, Samsuri AW, 2015. Characterization of nitrogen uptake pattern in Malaysian rice MR219at different growth stages using ^{15}N isotope. Rice Science. 22(5):250-254

Nasima J, Khanif M.Y., M. H. (2010). Maize response to biodegradable polymer and urease inhibitor coated urea. *International Journal of Agriculture and Biology 12(5)* , 773-776

Nasima J, Khanif MY, Hanafi MM, Wan Yunus WMZ, Dharejo KA.(2011) Role of inhibitors and biodregradable material in mitigation of nitrogen losses from fertilized lands. Afr. J. of Biotech. 10(8): 3504-3514

Nasima J. 2011. Doctor of Philosophy. Preparation and characterization of urea with coated-urea materials and their performance to reduce ammonia volatilization and improve crop production. Universiti Putra Malaysia,2011

O'Toole J.C. 2004. Rice and water: The final frontier. Paper presented at the First International Conference on rice for the future. Bangkok, Thailand

Ouzounidou G. 1995. Effect of copper on germination and sedling growth of *Minuarta, Silena, Alyssum* and *Thlaspi*. Biologia Plantarum. 37(3):411-416

Paddy Statistic of Malaysia 2013. Unit Perangkaan, Bahagian Perancangan, Teknologi Maklumat dan Komunikasi Jabatan Pertanian Semenanjung Malaysia.

Parker, J. 2011.“A special report on feeding the world.The 9-billion-people question,” *TheEconomist*, February 26, 2011.

Pandey A., Kumar A., Pandey D.S., Thongbam P.D. 2014. Rice quality under water stress. Indian Journal of Advances in Plant Research. 1(2):23-26

Rachid S., Kenneth L. M., Inez S-L., Ajay K., Stephen M.H., Gary A., Arvind K., 2011. Drought resistance improvement in rice: An integrated genetic and resource management strategy. Plant Prod. Sci. 14(1):1-14.

Randall P.J., Bouma D. 1973. Zinc deficiency, carbonic anhydrase, and photosynthesis in leaves of spinach. Plant Physiol. 52:229-232

Rahmatullah K., Ali R.G., Sohail M.K., Akber H.G. 2007. Effect of zinc application on rice yield under wheat rice system. Pakistan J. of Biol. Sci. 10(2):235-239

Rehman H.-U., Tariq A, M Farooq, A Wakeel, Rengel Z. 2012. Zinc nutrition in rice production systems: a review. Plant Soil.

Reichman SM., 2002. Plants and metal. In: The response of plants to metal toxiciy: A review focusing on copper, manganese and zinc. Melbourne, Australia. Australian Minerals & Energy Enviroment Foundation. pp: 16-18.

RICE: Nutrient disorder and nutrient management. Achim Dobermann and Thomas Fairhust. 2000. IRRI. vol. 1. pg 114

Roohani N., Hurrell R., Kelishadi R., Schulin R. 2013. Zinc and its importance for human health:An integrative review. J. Res. Med. Sci. 18(2):144-157

Rosmarina A.K. 2016a. Doctor of Philosophy. Evaluation of selected coated urea on nitrogen use efficiency of rice. Universiti Putra Malaysia,2016

Rosmarina A.K., Yusop M.K., Musa M.H., Hussin A. 2016b. Laboratory evaluation of metal elements urease inhibitor and DMPP nitrofication inhibitor on nitrogenous gas losses in selected rice soil. Water Air Soil Pollut. 227:232

Sadeghazadeh B. 2013. A review of zinc nutrition and plant breeding. J.of Soil Science and Plant Nutrition. 13(4):905-927

Saleh J., Najafi N., Oustan S., Aliasgharzad N., Ghaseemi-Golezani K. 2013. Effect of silicon, salinity and waterlogging on the extractable Zn, Cu,K and Na in sanly loam soil. Intl. J. Agric: Res&Rev. 3(1):56-64

Satorre. H.E.A., Slafer G., 2008. Ecology abd physiology of yield determination. Publisher Routledge. 1, 503

Sharma C.P., Kumar N., Bisht S.S. 1994. Effect of Zn deficiency on chlorophyll content, photosynthesis and water relations of cauliflower plants. Photosynthetica. 30:353-359

Shivay YS., Dinesh K, Prasad R. (2008) Relative efficiency of zinc sulfate and zinc oxide-coated urea in rice-wheat cropping system. Comm. in Soil Sc. and Plant Analyis. 39: 1154- 1167.

Sikuku P.A., Netondo G.W., Musyimi D.M., Onyango J.C. 2010. Effects of water deficit on days to maturity and yield of three Nerica rainfd rice varieties. ARPN J. Of Agricultural and Biological Science. 5(3): 1-9

Skoog F. 1940. Relationships between zinc and auxin in the growth of higher plants. Am. J. Bot.,27:939-951

Somani L.L. 2008.Micronutrients for soil and Plant Health, Agrotech Publishing Academy, 14-74.

Somayeh S., Majid A., Ebrahim A., Shahriyar B. 2013. Effect of drought stress at different growth stages on yield and yield component of rice plant. Persian Gulf Crop Protection. 2(2): 14-18

Sudha S., Stalin P. 2015. Effect of zinc on yield, quality and zinc content of rice genotypes. International J. of Farm Sci. 5(3):17-27

Thangarajan R., Bolan N.S., Naidu R., Surapaneni A. 2015. Effects of temperature and amendments on nitrogen mineralization in selected Australian soils. Environ Sci Pollut Res. 22:8834-8854

Verma T.S., Bhagat R.M., 1990. Zinc and nitrogen interaction in wheat grown in limed and unlimed acid alfisol. Fertilizer Research. 22:29-35

Vinod K., Yadav DS. Yadav DS. 1990. Effect of nitrogen sources and copper levels on yield levels on yield, nitrogen and copper contents of wheat (*Triticum aestivum* L.,) Plant and Soil 127:79-83

Wang H., Liu R.L., Jin J.Y., 2009. Effects of zinc and soil moisture on photosynthetic rate and chlorophyll fluorescence parameters of maize. Biologica Plantarium. 53(1):191-194

Wapnir R.A. 1998. Copper absorption and bioavailability. Am. J. Clin. Nutr., 67:1054s-1060s

Whitehead D.C.,2000. Nutrient elements in grassland: soil-plant-animal relationships. Chap9: Micronutrient cations: iron,mangaese, zinc, copper and cobalt. Cabi publishing.

Wu C., Yongming L., Limin Z. 2010. Variability of copper availability in paddy fields in relation to selected soil properties in southeast China. Geoderma. 156. 200-206

Xiong ZT, Liu C, Geng B. 2006**.** Phytotoxic effects of copper on nitrogen metabolism and plant growth in Brassica pekinensis Rupr. Ecotoxicol Environ Saf. 64(3):273-80.

Xu JK., Yang LX. Wang ZQ. Dong GC. Huang JY. Wang YL. 2006. Toxicity of copper on rice and accumulation of copper in rice grainin copper contaminated soil.Chemosphere. 62:602-607

Yang Z.X., Liu S.Q., Zheng D.W., Feng S.D. 2006. Effects of Cadmium, Zinc, and Lead on soil enzyme activities. Journal of Enviromental Science. 18(6):1135-1141

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

Yruela, Inmaculada. (2005) Copper in plants. Braz. J. Plant Physiol.17(1):145-156.

Zeng F., Ali S., Zhang H., Ouyang Y., Qiu B., Wu F., Zhang G. 2011. The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Enviromental Pollution. 159:84-91

Zhang LI., He XJ, Chen M, An RD, An XI and Li J. 2014 Responses of nitrogen metabolism to copper stress in Luffa cylindrica roots,. J. Soil Sci. Plant Nutr. 14(3):616-624

Zhu, B. and Alva, A.K. 1993.Effect of pH on growth and uptake of copper by swingle citrumelo seedling. Journal of Plant Nutrition. 16:1837-1845

Zulkefli M., Aini, Z., Razak, H., and Kamaruddin, A. 2004.Boron Deficiency in Direct Seeded Rice in KADA Region.*In* Proceeding, Soils 2004 Conference. April 2004. Penang, Malaysia. Malaysian Society of Soil Science (MSSS).