UNIVERSITI PUTRA MALAYSIA

EFFECTS OF MOLYBDENUM APPLICATION ON NUTRIENT UPTAKE AND YIELD OF RICE AND NITROGENASE ACTIVITY OF RHIZOBACTERIA

HAMED ZAKIKHANI

FP 2016 47

EFFECTS OF MOLYBDENUM APPLICATION ON NUTRIENT UPTAKE AND YIELD OF RICE AND NITROGENASE ACTIVITY OF RHIZOBACTERIA

By

HAMED ZAKIKHANI

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

June 2016

COPYRIGHT

DEDICATION

Every challenging work needs self-efforts as well as guidance of elders especially those who were very close to our heart.

This is dedicated to:

My parents

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

EFFECTS OF MOLYBDENUM APPLICATION ON NUTRIENT UPTAKE AND YIELD OF RICE AND NITROGENASE ACTIVITY OF RHIZOBACTERIA

By

HAMED ZAKIKHANI

June 2016

Chairman : Professor Mohd Khanif Yusop, PhD
Faculty : Agriculture

In tropical soils, the deficiency of Mo may be seen in the rice plants. Hence, elucidating the optimum levels of Mo in soil and plants will be helpful for understanding the plant growth. The current study was conducted to assess Mo status in soils and plants, and to determine the influences of Mo on in vitro nitrogenase activities of some plant growth promoting rihizobacteria (PGPR). Five rice cultivars (MR219, HASHEMI, MR232, FAJRE and MR253) and 4 levels of Mo (0, 0.01, 0.1, and 1.0 mg L^{-1}) were used for the first experiment. The highest Mo uptake in shoots (0.70 µg $plant^{-1}$) and roots (0.66 µg $plant^{-1}$) were seen in the MR232 at the highest level of Mo (1 mg L^{-1}) in solution culture. Iron rates in shoot decreased with increasing Mo levels in solution culture and reached 39.93 µg $plant^{-1}$ at the highest level of Mo. Also, phosphorus uptake in all cultivars increased with enhancing Mo in medium culture and reached highest (0.6 %) in cultivar MR232. In other experiment, Mo combination (0, 0.01, 0.05, 0.1, 0.5, 1, 1.5, 2, 2.5 mg L^{-1}) was applied to the growth medium contained four nitrogen fixation bacteria (UPMB10, UPMB12, Sb16 and R19). Nitrogenase activity enhanced with increasing Mo levels in growth medium of all bacteria strains except Sb16. The strongest correlation ($r = 0.78^{**}$, $p<0.01$) was found between Mo and ethylene production in UPB10, and the weakest one was seen in R19 ($r = 0.49^{*}$, $p<0.05$). The highest ethylene productions in UPMB10 (99.6 µmol mol^{-1} $hour^{-1}$), UPMB12 (87.2 µmol mol^{-1} $hour^{-1}$) and R19 (80.1 µmol mol^{-1} $hour^{-1}$) were seen in treatments contained 2.5 ppm Mo. We collected eleven soil series from two depths of Kedah and Kelantan paddy fields. Sequential extractions of soil Mo fractions indicated that Kranji series contained highest plant available amount of Mo (0.26 mg kg^{-1}) in comparison with other seven series of Kedah soils (surface layer), and highest medium plant available Mo (0.24

mg kg^{-1}) was seen in Rotan and Sedaka series of Kedah area (surface layer). In upper layers of Kedah soil series, we could not detect any acid soluble Mo (associated with calcium). In surface layers of Kelantan, highest amount of plant available Mo (0.23 mg kg^{-1}) was found in in Lating series but medium plant available of Mo (0.15 mg kg^{-1}) was obtained from Cempaka series. In lower depths of Kedah, Guar series contained highest plant available mount of Mo (0.28 mg kg^{-1}) and medium plant available rate of Mo (0.35 mg kg^{-1}) was seen in Rotan series. In lower layers of Kelantan, Lating series contained highest amount of plant available Mo (0.34 mg kg^{-1}) and medium plant available of Mo rate (0.07 mg kg^{-1}) was only found in Batu Hitam series. We found out that cation exchange capacity was positively correlated with total amount of Mo in upper layers of Kedah soil series ($r = 0.61$; $P \leq 0.05$), and no statistically correlation was found between Mo contents and soil properties in Kelantan soil series.

For the last experiment, we used foliar and soil application methods in order to determine the optimum Mo rate at which highest rice grain is produced. We found out that grain yield of rice was correlated with total shoot dry weight and plant height with r value of 0.53* and 0.74* in treatments sprayed with Mo. The greatest grain yield (21 g $plant^{-1}$) was seen in treatment of 5 mg Mo kg^{-1} in soil, and treatment of 30 µg Mo L^{-1} supplied as foliar.

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

KESAN MOLIBDENUM PERMOHONAN PENGAMBILAN NUTRIEN DAN HASIL NASI DAN NITROGENASE PEMEROLEHAN RHIZOBACTERIA

By

HAMED ZAKIKHANI

Jun 2016

Pengerusi : Profesor Mohd Khanif Yusop, PhD
Fakulti : Pertanian

Dalam tanah tropika, kekurangan Mo boleh dilihat dalam tanaman padi. Oleh itu, menjelaskan atas dasar tahap optimum Mo dalam tanah dan tumbuh-tumbuhan akan menjadi berguna untuk memahami pertumbuhan tumbuhan. Kajian ini telah dijalankan untuk menilai status Mo dalam tanah dan tumbuh-tumbuhan, dan untuk menentukan pengaruh Mo di dalam vitro aktiviti nitrogenase beberapa pertumbuhan tumbuhan menggalakkan rihizobacteria (PGPR). Five kultivar beras (MR219, HASHEMI, MR232, MR253 dan FAJRE) dan 4 tahap Mo (0, 0.01, 0.1, dan 1.0 mg L^{-1}) telah digunakan untuk percubaan pertama. The Mo pengambilan tertinggi dalam pucuk (0.70 µg $kilang^{-1}$) dan akar (0.66 µg tumbuhan $^{-1}$) dilihat di MR232 di peringkat tertinggi Mo (1 mg L^{-1}) dalam budaya penyelesaian. kadar zat besi dalam pucuk menurun dengan peningkatan tahap Mo dalam budaya penyelesaian dan mencapai 39.93 µg tumbuhan $^{-1}$ pada tahap tertinggi Mo. Juga, pengambilan fosforus di dalam semua kultivar meningkat dengan meningkatkan Mo dalam budaya sederhana dan mencapai tertinggi (0.6%) dalam kultivar MR232 . Dalam eksperimen lain, gabungan Mo (0, 0.01, 0.05, 0.1, 0.5, 1, 1.5, 2, 2.5 mg L^{-1}) telah digunakan untuk medium pertumbuhan yang terkandung empat bakteria nitrogen (UPMB10, UPMB12, Sb16 dan R19). Aktiviti nitrogenase dipertingkatkan dengan meningkatkan tahap Mo dalam medium pertumbuhan semua bakteria strain kecuali Sb16. Korelasi kuat (r = 0.78 **, $p<0.01$) didapati antara Mo dan pengeluaran etilena dalam UPB10, dan yang paling lemah dilihat dalam R19 (r = 0.49 *, $p<0.05$). Penghasilan etilena tertinggi di UPMB10 (99.6 µmol mol-1 jam-1), UPMB12 (87.2 µmol mol^{-1} jam^{-1}) dan R19 (80.1 µmol mol^{-1} jam^{-1}) telah dilihat dalam rawatan terkandung 2.5 mg L^{-1} Mo. Kami dikumpul sebelas siri tanah dari dua kedalaman sawah padi Kedah dan Kelantan. pengekstrakan berurutan tanah Mo pecahan menunjukkan bahawa siri Kranji terkandung tertinggi tumbuhan jumlah yang ada bagi Mo (0.26 mg kg^{-1}) berbanding dengan tujuh siri yang lain Kedah tanah (lapisan permukaan), dan paling tinggi kilang sederhana ada Mo (0.24 mg kg^{-1}) dilihat dalam Rotan dan Sedaka siri kawasan Kedah (lapisan permukaan). Dalam lapisan atas siri tanah Kedah, kami tidak dapat mengesan apa-apa larut Mo asid (yang

berkaitan dengan kalsium). Dalam lapisan permukaan Kelantan, jumlah tertinggi tumbuhan ada Mo (0.23 mg kg^{-1}) didapati di dalam Lating siri tetapi tumbuhan medium yang ada bagi Mo (0.15 mg kg-1) telah diperolehi dari siri Cempaka. Di kedalaman lebih rendah Kedah, siri Guar terkandung tumbuhan tinggi yang terdapat gunung Mo (0.28 mg kg^{-1}) dan sederhana kilang Kadar yang ada bagi Mo (0.35 mg kg^{-1}) telah dilihat dalam siri Rotan. Dalam lapisan bawah Kelantan, Lating siri terkandung jumlah tertinggi tumbuhan ada Mo (0.34 mg kg^{-1}) dan loji medium yang ada bagi Mo kadar (0.07 mg kg^{-1}) hanya dijumpai dalam siri Batu Hitam. Kami mendapati bahawa kapasiti pertukaran kation korelasi positif dengan Jumlah Mo di lapisan atas siri tanah Kedah ($r = 0.61$; $P \leq 0.05$), dan tidak ada korelasi statistik yang didapati antara kandungan Mo dan sifat-sifat tanah di Kelantan siri tanah.

Untuk percubaan terakhir, kami menggunakan kaedah permohonan foliar dan tanah untuk menentukan kadar Mo optimum di mana beras tertinggi dihasilkan. Kami mendapati bahawa hasil bijirin beras telah dikaitkan dengan jumlah berat menembak kering dan ketinggian tumbuhan dengan nilai r dari 0.53 * dan 0.74 * dalam rawatan disembur dengan Mo. The hasil bijirin besar (21 g $kilang^{-1}$) dilihat dalam rawatan 5 mg Mo kg^{-1} di dalam tanah, dan rawatan 30 µg Mo L^{-1} dibekalkan sebagai foliar.

ACKNOWLEDGEMENTS

First and foremost, I must acknowledge my limitless thanks to God, the Ever-Magnificent; the Ever-Thankful, for His helps and bless. I would never have been able to finish my dissertation without his guidance.

I would like to express the deepest appreciation to my committee chair Professor Doctor Mohd Khanif Yusop, for the patient guidance, encouragement and advice he has provided throughout my time as his student, he continually and persuasively conveyed a spirit of adventure in regard to research and scholarship. I have been extremely lucky to have a supervisor who cared so much about my work, and who responded to my questions and queries so promptly.

I would like to acknowledge with much appreciation my committee members, Prof. Dr. Mohamed Hanafi Musa and Assoc. Prof. Dr. Radziah Othman for their useful comments, remarks and engagement through the learning process of this thesis.

I would also like to thank my parents and my sister, Parnia, for their endless love and support.

I would like to thank Ms. Umi Kalthum Bt Asmaon as well for her assistance and guidance in the laboratory with this research. Last but not least, I would like to extend grateful thanks to all the members and staff of Land Management Department who helped me during my research.

This thesis was submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follow:

Mohd Khanif Yusop
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Mohamed Hanafi Musa
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Radziah Othman
Associated Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

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

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice- Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ______________________ Date: ______________________

Name and Matric No: Hamed Zakikhani, GS32715

Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ____________________
Name of
Chairman of
Supervisory
Committee ___________________

Signature: ________________
Name of
Member of
Supervisory
Committee _______________

Signature: ____________________
Name of
Member of
Supervisory
Committee ___________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

Mo	Molybdenum
MoO_4^{2-}	Molybdate
H_2MoO_4	Molybdic Acid
$HMoO_4$	Hydroxy dioxymolybdenum
MoS_2	Molibdenite
MoO_2	Molybdenum dioxide
MoO3	Molydenum trioxide
$CuMoO_4$	Copper Molybdenum tetraoxide
$ZnMoO_4$	Zinc Molybdenum tetraoxide
PbH_2MoO_4	Lead Molybdate
CaH_2MoO_4	Calcium Molybdate
$Fe(oH)_3$	Iron(III) oxide-hydroxide
Fe_2O_3	Iron(III) oxide
$CaSo_4.2H_2O$	Gypsum
PO_4^{3-}	Phosphate
$NaHCO_3$	Sodium Hydrogen Carbonate
NaOH	Sodium Hydroxide
HCL	Hydrochloric Acid
$HCLO_4$	Perchloric Acid
DMRT	Duncan Multiple Range Test
MOP	Muriate of potash
K_2O	Potassium oxide
HF	Hydrogen fluoride
$HCIO^{4-}$	Perchloric acid
HNO^{3-}	Nitric acid
NH_4OAC	Ammonium Acetate
ICP-EOS	Inductively coupled plasma optical emission spectroscopy
ICP-MS	Inductively coupled plasma mass spectrosmetry
ppm	Parts per million
$\mu g\ g^{-1}$	micro gram per gram
$mg\ g^{-1}$	milligram per gram
$kg\ ha^{-1}$	Kilogram per hectare
$\mu mol\ mol^{-1}\ hour^{-1}$	Micromol per Mol per hour
H	hours
µM	Micro Molar

mM	Milli molar
μg Mo L^{-1}	Microgrsm Molybdenum per liter
g $Plant^{-1}$	gram per plant
μg L^{1-}	microgram per kilogram
mg kg^{-1}	megagram per kilogram
W:v	Weight per volume
RCBD	Randomized complete block design
FD	Factorial Design
PCA	Principal Component Analysis
CEC	Cation Exchange Capacity
ANOVA	Analysis of variance
OM	Organic matter
°C	Centigrade
S.O.V	Source of Variation

CHAPTER 1

INTRODUCTION

Molybdenum (Mo) is important in ecosystems as a micronutrient for plants, animals and some microorganisms. The average concentration of Mo in the earth's crust varies from 1.0 to 2.3 mg kg^{-1} ranking it 53^{th} in crustal abundance (Krauskopf and Bird, 1979). Molybdenum has five possible oxidation states (II, III, IV, V, and VI). In nature, the oxidation states of IV and VI predominate but the VI state is the most stable form. It also has industrial use and is an important fertilizer element in some farming systems. Gupta (1997) mentioned that Mo could be found in four main fractions in soils as follows; 1) water-soluble (plant available), 2) adsorbed and fixed on oxides and hydroxides such as iron and aluminium, 3) solid phases of Mo , and 4) associated Mo with organic compounds. Molybdenum occurs combined with other elements in nature so that most common mineral of Mo, which is molybdenite (MoS_2), is found in granites, and the next most common mineral of Mo ($PbMoO_4$) is found in oxidized zones of mineral deposites (Gupta, 1997; Adriano, 2001). The main Mo supply (nearly 95%) is mined from porphyry deposits associated with intrusive igneous rocks but marine black shales, lignite and lignitic sandstone, coal and phosphorite deposits are also recognized to contain large amoutns of Mo (King *et al.*, 1973). Plant available and predominant aqueous species of Mo in natural systems is molybdate (MoO_4^{2-}). In soil at pH above 4, molybdate is the dominant aqueous species but at the pH below 4, hydrogen molybdate ($HMoO_4^{2-}$), Mo $(OH)_6^0$ and $HMo_2O_7^-$ are the prevailing forms(Cruywagen and De Wet, 1988). Mo ions are components of several enzymes, including nitrogenase, nitrate reductase, xanthine oxidoresuctase, aldehyde oxidase and sulfite oxidase (Hille *et al.*, 2011).

Nitrogenase enzyme is responsible for all biological nitrogen fixation activities. Since Mo is an essential element for nitrogen fixation, its absence can disrupt the biological fixation of nitrogen. Interaction between Mo and other nutrients is of great importance in plant nutrition and yield. In an experiment, application of Mo enhanced shoot phosphorus (P) uptake and root P concentration, and P increased shoot Mo concentration and uptake in rapeseed (Liu *et al.*, 2010). They also concluded that co-application of Mo and P was necessary to improve plant growth. In soil solution, higher concentrations of nitrate are presented to increase the Mo requirement by plants (Gupta and Lipsett, 1982) but higher concentrations of ammonium may reduce uptake of Mo. The nitrate positive influence on uptake of Mo can be due to pH enhancement and release of OH^- ions. Also, greater uptake of ammonium may release more H^+ ions in the rhizosphere and reduce pH, consequently declining Mo uptake by the plants. In a pot experiment, application of calcium (Ca) fertilizer increased the uptake of Mo in tobacco (Eivazi *et al.*, 1983). They also added that the effect of Ca fertilizer was greater when higher levels of sodium molybdate fertilizer were applied. Iron accumulation in plants seems to be inversely proportional with application of Mo. Hanger (1965) reported that Mo-induced apical chlorosis and stunting in red clover were eliminated once chelated iron was added to growth medium.

Availability of Mo to the plants are influenced by some factors, including soil pH, organic compounds, iron and alumiun oxides, soil texture and type and drainage. When pH increases in soils, availability of essential micronutrients declines but molybdenum's availability increases hence, in alkaline soils, availability of Mo increases and becomes more available to the plants. In acid soils, mobility of Mo reduces as its adsorption to sorbent sites increases (Reddy *et al.*, 1997). Molybdenum acts like an anion in soil and illustration of its adsorption mechanism(s) on organic matter is difficult. However, some workers reported that a close relationship between levels of adsorbed Mo and organic matter was seen (Karimian and Cox, 1978). Also, Kaiser et al (2005) mentioned that poorly drained soils (peat marshes) tend to accumulate high concentrations of molybdate, but, by contrast, well-drained sandy soils leach significant levels of applied Mo. Penetration of molybdate into microspores and iron oxide interdomains can be resulted in immobilisation of molybdate. Lang and Kaupenjohann (2003) demonstrated that the rate of molybdate immobilisation by iron oxides surfaces is dependent on pore system geometry and crystallinity of iron oxides (Lang and Kaupenjohann, 2003). Also, there are some soil factors affecting the thresholds of Mo toxicity. McGrath et al (2010) concluded that ammonium oxalate-extractable iron and organic carbon were the best predictors of toxicity threshold values for Mo.

Diazotrophic bacteria, such as Bacillus genera, belong to plant growth promoting rhizobateria. These bacteria are able to convert dinitrogen into ammonia which is used by the plants. Molybdenum is known as an essential micronutrient for the biological nitrogen fixers and its deficiency limit their biological nitrogen-fixing activities (Campo *et al.*, 2000). In a field experiment, inoculation Mo-rich seeds produced crops with enhanced Mo and nitrogen rates in seeds and higher seed yield. They also mentioned that foliar applications of Mo increased concentrations of Mo in soybean seed by 3000% in comparison with regular grains produced without any supply of Mo (Campo *et al.*, 2009).

1.1 Justification

Molybdenum deficiency is common in acid soils and it has crucial roles in plants and microorganisms via molybdoenzymes. Research data on rice responses to Mo are not as extensive as those of other micronutrients like zinc, copper, boron, iron, and manganese. Symptoms of Mo deficiency are more common than toxicity in crops under certain soils. If high concentrations of Mo are present, depressing effect of Mo on physiological availability of copper will cause molybdenosis in ruminants (Majak *et al*., 2006). Nevertheless toxicity of Mo is uncommon and is seen only when large concentrations of Mo are present. Antagonistic impacts of Mo on absorption of other nutrients by the plants can be considered as nutrient-suppression effect and also synergistic influences of Mo can produce a catalysing effect on uptake of nutrients by the plants in environments. Availability of Mo in acid soils is very low. Since Malaysian soils are predominantly acidic, evaluation of Mo in both soils and plants could be vitally important. In line with the national agriculture policy, Malaysia wishes to increase rice self-sufficiency (Liew *et al*., 2010). There has been no report on Mo deficiency in crop plants productions in Malaysia, and this may account for the lack of specific information on soil and plant Mo status in data resources. Hence, understanding the Mo status in rice plants and paddy fields, and study of its influences on other nutrients uptake, are of importance. We hypothesized that molybdenum application increase the yield of rice. A particular focus was on quantifying the concentrations of Mo within the rice cultivars. We also hypothesized that Mo availability in irrigated paddy soils are dependent on chemical and physical characteristics of soils. Another hypothesis was that Mo application improves nitrogenase activity of some soil rhizobacteria.

1.2 Objectives

1. To evaluate Mo status of selected rice soils of Malaysia
2. To determine the effects of rice varieties on Mo nutrition of rice
3. To determine the effects of Mo on nitrogenase activities of selected PGPR
4. To determine the optimum Mo rate at which highest rice grain yield is produced

BIBLIOGRAPHY

ADB, 2009. The economics of climate change in Southeast Asia: a regional review. Asian Development Bank, Manila.

Adriano, D.C., 2001. Trace elements in terrestrial environments: biogeochemistry, bioavailability, and risks of metals. Springer.

Agarwala, S., Chatterjee, C., Sharma, P., Sharma, C., Nautiyal, N., 1979. Pollen development in maize plants subjected to molybdenum deficiency. Canadian Journal of Botany 57, 1946-1950.

Agarwala, S., Sharma, C., Farooq, S., Chatterjee, C., 1978. Effect of molybdenum deficiency on the growth and metabolism of corn plants raised in sand culture. Canadian Journal of Botany 56, 1905-1908.

Agarwala, S.C., Chatterjee, C., Sharma, C.P., Nautiyal, N., 1989. Copper-molybdenum interaction in maize. Soil Science and Plant Nutrition 35, 435-442.

Alam, F., Kim, T.Y., Kim, S.Y., Alam, S.S., Pramanik, P., Kim, P.J., Lee, Y.B., 2015. Effect of molybdenum on nodulation, plant yield and nitrogen uptake in hairy vetch (Vicia villosa Roth). Soil Science and Plant Nutrition, 1-12.

Allen, M.B., Arnon, D.I., 1955. Studies on nitrogen-fixing blue-green algae. I. Growth and nitrogen fixation by Anabaena cylindrica Lemm. Plant Physiology 30, 366.

Alloway, B.J., 2013. Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability, Environmental Pollution. Springer.

Amrhein, C., Mosher, P., Brown, A., 1993. The effects of redox on Mo, U, B, V and As solubility in evaporation pond soils.. Soil Science 155, 249-255.

Anderson, A., Spencer, D., 1950. Molybdenum in nitrogen metabolism of legumes and non-legumes. Australian Journal of Biological Sciences 3, 414-430.

Anderson, A.j., 1956. Molybdenum deficiencies in legumes in Australia. Soil Science 81, 173-182.

Aubert, H., Pinta, M., 1980. Trace elements in soils. Elsevier.

Bala, P., Hossain, S., 2008. Yield and quality of rice as affected by molybdenum applied with chemical fertilizers and organic matter. Journal of Agriculture & Rural Development 6, 19-23.

Baldwin, K., Childs, N., Dyck, J., Hansen, J., 2012. Southeast Asia's Rice Surplus. Econimic Research Service, USA, pp. 2-37.

Barrow, N., 1970. Comparison of the adsorption of molybdate, sulfate and phosphate by soils. Soil Science 109, 282-288.

Barrow, N., Cartes, P., Mora, M., 2005. Modifications to the Freundlich equation to describe anion sorption over a large range and to describe competition between pairs of ions. European Journal of Soil Science 56, 601-606.

Barshad, I., 1951. Factors affecting the molybdenum content of pasture plants: II. Effect of soluble phosphates, available nitrogen, and soluble sulfates. Soil Science 71, 387-398.

Basak, A., Mandal, L., Haldar, M., 1982. Interaction of phosphorus and molybdenum in relation to uptake and utilization of molybdenum, phosphorus, zinc, copper and manganese by rice. Plant and Soil 68, 261-269.

Baxter, I., Muthukumar, B., Park, H.C., Buchner, P., Lahner, B., Danku, J., Zhao, K., Lee, J., Hawkesford, M.J., Guerinot, M.L., 2008. Variation in molybdenum content across broadly distributed populations of Arabidopsis thaliana is controlled by a mitochondrial molybdenum transporter (MOT1). PLoS Genetics 4.

Becker, D., Stanke, R., Fendrik, I., Frommer, W.B., Vanderleyden, J., Kaiser, W.M., and Hedrich, R., 2002. Expression of the HN4 +-transporter gene LEAMT1;2 is induced in tomato roots upon association with N2 fixing bacteria. Planta 215, 424-429.

Bennett, W.F., 1993. Nutrient deficiencies and toxicities in crop plants. American Phytopathological Society.

Berger, K.C., Pratt, P.F., 1963. Advances in secondary and micronutrient fertilization. Fertilizer technology and usage, 287-340.

Berry, J.A., Reisenauer, H., 1967. The influence of molybdenum on iron nutrition of tomato. Plant and soil 27, 303-313.

Bertine, K., 1972. The deposition of molybdenum in anoxic waters. Marine Chemistry 1, 43-53.

Bezzate, S., Aymerich, S., Chambert, R., Czarnes, S., Berge, O., Heulin, T., 2000. Disruption of the Paenibacillus polymyxa levansucrase gene impairs its ability to aggregate soil in the wheat rhizosphere. Environmental Microbiology 2, 333-342.

Bibak, A., Borggaard, O.K., 1994. Molybdenum adsorption by aluminum and iron oxides and humic acid. Soil science 158, 323-328.

Boland, M., 1981. NAD+: xanthine dehydrogenase from nodules of navy beans: partial purification and properties. Biochemistry international 2, 567-574.

Bondareva, T., Khurum, K.D., Sheudzhen, A.K., Onishchenko, L., 2010. Yield of rice grain and alfalfa green mass with application of microfertilizers. Russian Agricultural Sciences 36, 96-99.

Bonilla, I., Cadahia, C., Carpena, O., Hernando, V., 1980. Effects of boron on nitrogen metabolism and sugar levels of sugar beet. Plant and Soil 57, 3-9.

Bottrell, D.G., Schoenly, K.G., 2012. Resurrecting the ghost of green revolutions past: the brown planthopper as a recurring threat to high-yielding rice production in tropical Asia. Journal of Asia-Pacific Entomology 15, 122-140.

Brennan, R., 2006. Residual value of molybdenum for wheat production on naturally acidic soils of Western Australia. Animal Production Science 46, 1333-1339.

Brodrick, S.J., Sakala, M., Giller, K.E., 1992. Molybdenum reserves of seed, and growth and N2 fixation by Phaseolus vulgaris L. Biology and fertility of Soils 13, 39-44.

Brookins, D.G., 1988. Eh-pH diagrams for geochemistry. Springer-Verlag Berlin.

Burkhard, B., Müller, A., Müller, F., Grescho, V., Anh, Q., Arida, G., Bustamante, J.V.J., Van Chien, H., Heong, K., Escalada, M., 2015. Land cover-based ecosystem service assessment of irrigated rice cropping systems in southeast Asia—An explorative study. Ecosystem Services 14, 76-87.

Burton, E.D., Bush, R.T., Johnston, S.G., Sullivan, L.A., Keene, A.F., 2011. Sulfur biogeochemical cycling and novel Fe–S mineralization pathways in a tidally re-flooded wetland. Geochimica et Cosmochimica Acta 75, 3434-3451.

Cairns, A., Kritzinger, J., 1992. The effect of molybdenum on seed dormancy in wheat. Plant and soil 145, 295-297.

Calonego, J.C., Ramos Junior, E.U., Barbosa, R.D., Leite, G.H.P., Grassi Filho, H., 2010. Adubação nitrogenada em cobertura no feijoeiro com suplementação de molibdênio via foliar. Revista Ciência Agronômica 41, 334-340.

Campo, R.J., Albino, U.B., Hungria, M., 2000. Importance of molybdenum and cobalt to the biological nitrogen fixation. Nitrogen Fixation: From Molecules to Crop Productivity. Springer, pp. 597-598.

Campo, R.J., Araujo, R.S., Hungria, M., 2009. Molybdenum-enriched soybean seeds enhance N accumulation, seed yield, and seed protein content in Brazil. Field crops research 110, 219-224.

Candela, M., Hewitt, E., 1957. Molybdenum as a plant nutrient. IX. The effects of different molybdenum and manganese supplies on yield and on the uptake and distribution of molybdenum in tomato plants grown in sand culture. Journal of Horticultural Science 32, 149-161.

Cardenas, J., Mortenson, L.E., 1975. Role of molybdenum in dinitrogen fixation by Clostridium pasteurianum. Journal of Bacteriology 123, 978-984.

Chakraborty, S., Pradip, K.D., Biswajit, G., Sarmah, K.K., Barman, B., 2010. Quantitative genetic analysis for yield and yield components in boro rice (Oryza sativa L.). Notulae Scientia Biologicae 2, 117.

Chappell, R., Petersen, K.K., 1978. Molybdenum in the Environment. Soil Science 125, 334.

Chatterjee, C., Nautiyal, N., Agarwala, S., 1985. Metabolic changes in mustard plants associated with molybdenum deficiency. New Phytologist 100, 511-518.

Chesworth, W. 2007. Encyclopedia of Soil Science. Nature. Science and Busines Media. 512-800.

Costa, D.S., Barbosa, R.M., Oliveira, J.S., Sa, M.E., 2014. Foliar Application of Calcium and Molybdenum in Common Bean Plants: Yield and Seed Physiological Potential. Agricultural Sciences 5, 1037.

Cruywagen, J., De Wet, H., 1988. Equilibrium study of the adsorption of molybdenum (VI) on activated carbon. Polyhedron 7, 547-556.

Curatti, L., Ludden, P.W., Rubio, L.M., 2006. NifB-dependent in vitro synthesis of the iron–molybdenum cofactor of nitrogenase. Proceedings of the National Academy of Sciences 103, 5297-5301.

David, K., Apte, S., Banerji, A., Thomas, J., 1980. Acetylene reduction assay for nitrogenase activity: gas chromatographic determination of ethylene per sample in less than one minute. Applied and Environmental Microbiology 39, 1078-1080.

Davies, E.B., 1956. Factors affecting molybdenum availability in soils. Soil Science 81, 209-221.

Deo, C., Kothari, M., 2002. Effect of modes and levels of molybdenum application on grain yield protein content and nodulation of chickpea grown on loamy sand soil. Communications in soil science and plant analysis 33, 2905-2915.

DOA, 2013. Paddy statistics of Malaysia 2013, annual report. In: Agriculture, D.O. Department of Agriculture, Petaling Jaya, Malaysia.

Dobbelaere, S., Vanderleyden, J., Okon, Y., 2003. Plant growth-promoting effects of diazotrophs in the rhizosphere. Critical Reviews in Plant Sciences 22, 107-149.

Döbereiner, J., Pedrosa, F.O., 1987. Nitrogen-Fixing bacteria in nonleguminous crop plants. Science Tech, Madison, USA.

Domingo, L.E., Kyuma, K., 1983. Trace elements in tropical Asian paddy soils: I. Total trace element status. Soil Science and Plant Nutrition 29, 439-452.

Eady, R.R., 1996. Structure-function relationships of alternative nitrogenases. Chemical Reviews 96, 3013-3030.

Egener, T., Hurek, T., Reinhold-Hurek, B., 1999. Endophytic expression of nif genes of Azoarcus sp. strain BH72 in rice roots. Molecular Plant-Microbe Interactions 12, 813-819.

Eivazi, F., Sims, J., Casey, M., Johnson, G., Leggett, J., 1983. Growth and molybdenum concentration of burley tobacco as influenced by potassium, molybdenum, and chloride in transplant fertilizer solutions. Canadian Journal of Plant Science 63, 531-538.

El-Samad, H.A., El-Komy, H., Shaddad, M., Hetta, A., 2005. Effect Of Molybdenum On Nitrogenase And Ni-Trate Reductase Activities Of Wheat Inocu-Lated With Azospirillum Brasilense Grown Un-Der Drought Stress. Gen. Appl. Plant Physiology 31, 43-54.

Elliott, B.B., Mortenson, L., 1975. Transport of molybdate by Clostridium pasteurianum. Journal of Bacteriology 124, 1295-1301.

Enzmann, R., 1972. Molybdenum: Element and geochemistry. The encyclopedia of geochemistry and environmental sciences, IV A. Van Nostrand Reinhold Co, p. 753.

Fageria, N., 2001. Nutrient management for improving upland rice productivity and sustainability. Communications in Soil Science and Plant Analysis 32, 2603-2629.

Fageria, N., 2003. Plant tissue test for determination of optimum concentration and uptake of nitrogen at different growth stages in lowland rice. Communications in soil science and plant analysis 34, 259-270.

Fageria, N., 2007. Yield physiology of rice. Journal of Plant Nutrition 30, 843-879.

Fageria, N., 2009. The use of nutrients in crop plants. CRC Press, Taylor & Francis Group LLC, United States of America.

Fageria, N., Baligar, V., 2001. Lowland rice response to nitrogen fertilization. Communications in Soil Science and Plant Analysis 32, 1405-1429.

Fageria, N., Carvalho, G., Santos, A., Ferreira, E., Knupp, A., 2011. Chemistry of lowland rice soils and nutrient availability. Communications in soil science and plant analysis 42, 1913-1933.

Fageria, N., Filho, M.B., Moreira, A., Guimaraes, C., 2009b. Foliar fertilization of crop plants. Journal of plant nutrition 32, 1044-1064.

Fageria, N., Slaton, N., Baligar, V., 2003. Nutrient management for improving lowland rice productivity and sustainability. Advances in Agronomy 80, 63-152.

Fageria, N., Stone, L., Santos, A., 2015. Molybdenum Requirements of Dry Bean with and without Liming. Communications in Soil Science and Plant Analysis, 1-14.

FAO. 1999. Country pasture and forage resource profiles: Malaysia. Compiled by: Wong Choi Chee and Chen Chin Peng. Ed: H M Shelton, FAO,Rome. (http://www.fao.org/ag/agp/agpc/doc/counprof/malaysia.htm).

Favre, F., Tessier, D., Abdelmoula, M., Genin, J., Gates, W., Boivin, P., 2002. Iron reduction and changes in cation exchange capacity in intermittently waterlogged soil. European Journal of Soil Science 53, 175-183.

Ferreira, A., Araujo, G., Cardoso, A., Fontes, P., Vieira, C., 2003. Diagnose do estado nutricional molíbdico do feijoeiro em razão do molibdênio contido na semente e da sua aplicação foliar. Current Agricultural Science and Technology 9.

Fitzpatrick, K.L., Tyerman, S.D., Kaiser, B.N., 2008. Molybdate transport through the plant sulfate transporter SHST1. FEBS letters 582, 1508-1513.

Fox, P.M., Doner, H.E., 2003. Accumulation, release, and solubility of arsenic, molybdenum, and vanadium in wetland sediments. Journal of Environmental Quality 32, 2428-2435.

Franco, A., Day, J., 1980. Effects of lime and molybdenum on nodulation and nitrogen fixation of Phaseolus vulgaris L. in acid soils of Brazil. Turrialba 30, 99-105.

Franco, A., Munns, D., 1981. Response of Phaseolus vulgaris L. to molybdenum under acid conditions. Soil Science Society of America Journal. 45, 1144-1148.

Gerloff, G.C., Stout, P., Jones, L.P., 1959. Molybdenum-Manganese-Iron Antagonisms in the Nutrition of Tomato Plants. Plant physiology 34, 608.

Glenn, F., Daynard, T., 1974. Effects of genotype, planting pattern, and plant density on plant-to-plant variability and grain yield of corn. Canadian Journal of Plant Science 54, 323-330.

Gnanamanickam, S. S. 2006. Plant-associated bacteria. Heidelberg, Springer, Germany. Vol 1, 195-231.

Goldberg, S., Forster, H., Godfrey, C., 1996. Molybdenum adsorption on oxides, clay minerals, and soils. Soil Science Society of America Journal 60, 425-432.

Goldberg, S., Johnston, C.T., Suarez, D.L., Lesch, S.M., 2007. Mechanism of molybdenum adsorption on soils and soil minerals evaluated using vibrational spectroscopy and surface complexation modeling. Developments in Earth and Environmental Sciences 7, 235-266.

Graham, L., Maier, R.J., 1987. Variability in molybdenum uptake activity in Bradyrhizobium japonicum strains. Journal of Bacteriology 169, 2555-2560.

Gubler, W., Grogan, R., Osterli, P., 1982. Yellows of melons caused by molybdenum deficiency in acid soil. Plant Diseases.

Gupta, D.D., Basuchaudhuri, P., 1977. Molybdenum nutrition of rice under low and high nitrogen level. Plant and Soil 46, 681-685.

Gupta, U.C., 1997. Molybdenum in agriculture. Cambridge University Press.

Gupta, U.C., Lipsett, J., 1982. Molybdenum in Soils, plants and Animals. Advances in agronomy 34, 73.

Gupta, V., Kala, R., 1980. Effect of Cu and Mo on Cu/Mo ratio and their concentration in different organs of cowpeas (Vigna sinensis L.). Plant and Soil 56, 235-241.

Gupta, V., Mehla, D., 1979. Copper, manganese and iron concentration in berseem (Trifolium Alexandrinum) and coppermolybdenum ratio as affected by molybdenum in two types of soil. Plant and Soil 51, 597-602.

Gupta, V., Mehla, D., 1980. Influence of sulphur on the yield and concentration of copper, manganese, iron and molybdenum in berseem (Trifolium alexandrinum) grown on two different soils. Plant and Soil 56, 229-234.

Gurley, W.H., Giddens, J., 1969. Factors affecting uptake, yield response, and carryover of molybdenum in soybean seed. Agronomy Journal 61, 7-9.

Hagstrom, G., Berger, K., 1963. Molybdenum status of three Wisconsin soils and its effect on four legume crops. Agronomy Journal 55, 399-401.

Hanger, B., 1965. The influence of iron upon the toxicity of manganese, molybdenum, copper, and boron in red clover (Trifolium pratense L.). Journal of the Australian Institute of Agricultural Science 31, 315-317.

Hardy, R.W., Holsten, R., Jackson, E., Burns, R., 1968. The acetylene-ethylene assay for N2 fixation: laboratory and field evaluation. Plant Physiology 43, 1185-1207.

Havemeyer, A., Bittner, F., Wollers, S., Mendel, R., Kunze, T., Clement, B., 2006. Identification of the missing component in the mitochondrial benzamidoxime prodrug-converting system as a novel molybdenum enzyme. Journal of Biological Chemistry 281, 34796-34802.

Hedley, M.J., Stewart, J., Chauhan, B., 1982. Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. Soil Science Society of America Journal 46, 970-976.

Helz, G., Miller, C., Charnock, J., Mosselmans, J., Pattrick, R., Garner, C., Vaughan, D., 1996. Mechanism of molybdenum removal from the sea and its concentration in black shales: EXAFS evidence. Geochimica et Cosmochimica Acta 60, 3631-3642.

Hernandez, J.A., George, S.J., Rubio, L.M., 2009. Molybdenum trafficking for nitrogen fixation. Biochemistry 48, 9711-9721.

Hewitt, E., Gundry, C., 1970. The molybdenum requirement of plants in relation to nitrogen supply. Journal of Horticultural Science 45, 351-358.

Hille, R., Nishino, T., Bittner, F., 2011. Molybdenum enzymes in higher organisms. Coordination Chemistry Reviews 255, 1179-1205.

Hoh, R., 2008. Malaysian Grain and Feed Annual. 2008. Foreign Agricultural Service, USA.

Hoh, R., 2011. Malaysian Grain and Feed Anuual. 2011. Foreign Agricultural Service, USA.

Horstmann, J.L., Denison, W., Silvester, W., 1982. 15N2 Fixation and Molybdenum Enhancement of Acetylene Reduction by Lobaria Spp. New Phytologist 92, 235-241.

Jackson, W.A., 1967. Physiological effects of soil acidity. In: Pearson, R.W., Adams, F. (Eds.), Soil Acidity and Liming. American Society of Agronomy, madison, USA.

Jones, G., Belling, G., 1967. The movement of copper, molybdenum, and selenium in soils as indicated by radioactive isotopes. Crop and Pasture Science 18, 733-740.

Jones, J.B., 1965. Molybdenum content of corn plants exhibiting varying degrees of potassium deficiency. Science 148, 94-94.

Jones Jr, J, B., 1991. Plant tissue analysis in micronutrients. In: Mortvedt, J. (Ed.), Micronutrients in agriculture. Soil Science Society of America, Madison, USA, pp. 477-521.

Jones Jr, J.B., Case, V.W., Westerman, R., 1990. Sampling, handling and analyzing plant tissue samples. Soil testing and plant analysis., 389-427.

Jones, L., 1956. Interaction of molybdenum and iron in soils. Science 123, 1116.

Kaiser, B.N., Gridley, K.L., BRADY, J.N., Phillips, T., Tyerman, S.D., 2005. The role of molybdenum in agricultural plant production. Annals of botany 96, 745-754.

Kannan, S., 2010. Foliar fertilization for sustainable crop production. Genetic engineering, biofertilisation, soil quality and organic farming. Springer, pp. 371-402.

Kannan, S., Ramani, S., 1978. Studies on molybdenum absorption and transport in bean and rice. Plant physiology 62, 179-181.

Karimian, N., Cox, F., 1978. Adsorption and extractability of molybdenum in relation to some chemical properties of soil. Soil Science Society of America Journal 42, 757-761.

Kevresan, S., Petrovic, N., Popovic, M., Kandrac, J., 2001. Nitrogen and protein metabolism in young pea plants as affected by different concentrations of nickel, cadmium, lead, and molybdenum. Journal of plant Nutrition 24, 1633-1644.

Kim, K. Y., Jordan, D., & McDonald, G. A. 1998. Enterobacter agglomerans, phosphate solubilizing bacteria, and microbial activity in soil: effect of carbon sources. Soil Biology and Biochemistry, 30, 995-1003.

King, R.U., Shawe, D.R., MacKevett, E.M.J., 1973. Molybdenum. In: Albert, B.D., Pratt, W.P. (Eds.), United States Mineral Resources. US Government Printing Office, USA, pp. 425-435.

Kirby, J.K., McLaughlin, M.J., Ma, Y., Ajiboye, B., 2012. Aging effects on molybdate lability in soils. Chemosphere 89, 876-883.

Kirsch, R.K., Harward, M., Petersen, R., 1960. Interrelationships among iron, manganese, and molybdenum in the growth and nutrition of tomatoes grown in culture solution. Plant and Soil 12, 259-275.

Kloepper, J. W., and Schroth, M. N. 1978. Plant growth promoting rhizobacteria on radishes. In Proceedings of the fourth International Conference on Plant Pathogenic Bacteria. Argers, France: Station de Pathologie Vegetale et Phytobacteriologyie, INRA. Vol. 2, 879-892

Kloepper, J. W., Zablokovicz, R. M., Tipping, E. M., Lifshitz, R. 1991. Plant growth promotion mediated by bacterial rhizosphere colonizers. In D. L. Keister & P. B. Cregan (Eds.). The rhizosphere and plant growth. The Netherlands: Kluwer Academic Publishers. 315-326

Kozmin, S.G., Leroy, P., Pavlov, Y.I., Schaaper, R.M., 2008. YcbX and yiiM, two novel determinants for resistance of Escherichia coli to N ‐ hydroxylated base analogues. Molecular Microbiology 68, 51-65.

Krauskopf, K.B., Bird, D.K., 1979. Introduction to geochemistry. McGraw-Hill New York, USA.

Kubota, J., 1977. Molybdenum status of United States soils and plants. In: Petersen, W.R.C.a.K.K. (Ed.), Molybdenum in the Environment, United States of America, p. 812.

Kubota, J., Lemon, E., Allaway, W., 1963. The effect of soil moisture content upon the uptake of molybdenum, copper, and cobalt by alsike clover. Soil Science Society of America Journal 27, 679-683.

Kumar, V., Singh, M., 1980. Interactions of sulfur, phosphorus, and molybdenum in relation to uptake and utilization of phosphorus by soybean. Soil Science 130, 26-31.

Kunc, F., and Macura, J. 1988. Mechanisms of adaptation and selection of microorganisms in the soil. In V. Vancura & F. Kunc (Eds.). Soil Microbial Associations. Elsevier: Amsterdam, 281-299

Lang, F., Kaupenjohann, M., 2003. Immobilisation of molybdate by iron oxides: effects of organic coatings. Geoderma 113, 31-46.

Lebuhn, M., Heulin, T., Hartmann, A., 1997. Production of auxin and other indolic and phenolic compounds by Paenibacillus polymyxa strains isolated from different proximity to plant roots. FEMS Microbiology Ecology 22, 325-334.

Lefroy, R.D.B., Mamaril, C.P., Blair, G.J., Gonzales, P.J., 1992. Scope 48-Sulphur Cycling on the Continents. Wiley.

Leung, J., Giraudat, J., 1998. Abscisic acid signal transduction. Annual review of plant biology 49, 199-222.

Liew, Y., Omar, S.S., Husni, M., Abidin, M.Z., Abdullah, N., 2010. Effects of Micronutrient Fertilizers on the Production of MR219 (*Oryza sativa* **L**.). Malaysian Journal of Soil Science 14, 71-82.

Lilienfein, J., Wilcke, W., Ayarza, M.A., Vilela, L., do Carmo Lima, S., Zech, W., 2000. Chemical fractionation of phosphorus, sulphur, and molybdenum in Brazilian savannah Oxisols under different land use. Geoderma 96, 31-46.

Lindsay, W.L., 1979. Chemical equilibria in soils. John Wiley and Sons Ltd.

Liu, H., Hu, C., Hu, X., Nie, Z., Sun, X., Tan, Q., Hu, H., 2010. Interaction of molybdenum and phosphorus supply on uptake and translocation of phosphorus and molybdenum by Brassica napus. Journal of plant nutrition 33, 1751-1760.

Liu, P., Yang, Y., Xu, G., Fang, Y., Yang, Y., Kalin, R., 2005. The effect of molybdenum and boron in soil on the growth and photosynthesis of three soybean varieties. Plant Soil Environ 51, 197-205.

Loue, A., 1980. The interaction of potassium with other growth factors, particularly with other nutrients. Potassium fertilization in agricultural practice (extracted from Proc. 11th Congr. Int. Potash Institute). IPI Research Topics, pp. 67-93.

MacKay, D., Chipman, E., Gupta, U., 1966. Copper and molybdenum nutrition of crops grown on acid sphagnum peat soil. Soil Science Society of America Journal 30, 755-759.

Majak, W., Steinke, D., Lysyk, T., Ogilvie, K., McGillivray, J., 2006. Efficacy of copper supplementation in the prevention of molybdenosis in cattle. Rangeland Ecology & Management 59, 285-292.

Malla, R.M., Padmaja, B., Malathi, S., jalapathi, R.L., 2007. Effects of micronutrients on growth and yield of pigeonpea. Journal of Semi-Arid Tropical Agriculture 5, 1-3.

Mandai, B., Pal, S., Mandai, L., 1998. Effect of molybdenum, phosphorus, and lime application to acid soils on dry matter yield and molybdenum nutrition of lentil. Journal of plant nutrition 21, 139-147.

Marschner, H., 1995. Mineral nutrition of higher plants. 2nd San Diego. CA. Academic Press.

Martens, D., Westermann, D., 1991. Fertilizer application for correcting micronutrient deficiencies. In: Mortvedt, J. (Ed.), Micronutrients in Agriculture. Soil Science Society of America, USA, pp. 549-582.

Martin, S., Saco, D., Alvarez, M., 1995. Nitrogen metabolism in Nicotian a rustica L. grown with molybdenum. II. flowering stage. Communications in Soil Science & Plant Analysis 26, 1733-1747.

Masalha, J., Kosegarten, H., Elmaci, O., & Mengel, K. 2000. The central role of microbial activity for iron acquisition in maize and sunflower. Biology and Fertility of Soils, 30, 433-439.

Maynard, D.N., 1979. Nutritional disorders of vegetable crops: a review. Journal of Plant Nutrition 1, 1-23.

McBride, M., Richards, B., Steenhuis, T., Spiers, G., 2000. Molybdenum uptake by forage crops grown on sewage sludge-amended soils in the field and greenhouse. Journal of Environmental Quality 29, 848-854.

McGrath, S., Mico, C., Curdy, R., Zhao, F., 2010. Predicting molybdenum toxicity to higher plants: Influence of soil properties. Environmental Pollution 158, 3095-3102.

Mei, Y., Lei, S., Fang-Sen, X., Jian-Wei, L., Yun-Hua, W., 2009. Effects of B, Mo, Zn, and their interactions on seed yield of rapeseed (Brassica napus L.). Pedosphere 19, 53-59.

Mendel, R.R., Hänsch, R., 2002. Molybdoenzymes and molybdenum cofactor in plants. Journal of Experimental Botany 53, 1689-1698.

Mendel, R.R., Kruse, T., 2012. Cell biology of molybdenum in plants and humans. Biochimica et Biophysica Acta (BBA)-Molecular Cell Research 1823, 1568-1579.

Mengel, K., Kosegarten, H., Kirkby, E.A., Appel, T., 2001. Principles of plant nutrition. Springer Science & Business Media.

Millikan, C., 1948. Antagonism between molybdenum and certain heavy metals in plant nutrition. Nature 161, 528.

MMD, 2010. Malaysian Meterological Department. In: Department, M.M. (Ed.). Malaysian Meterological Department, Malaysia.

Moore Jr, P., Patrick Jr, W., 1991. Aluminium, boron and molybdenum availability and uptake by rice in acid sulfate soils. Plant and soil 136, 171-181.

Moraghan, J., Mascagni Jr, H., 1991. Environmental and soil factors affecting micronutrient deficiencies and toxicities. In: Mortvedt, J., Giordano, P., Lindsay, W.L. (Eds.), Micronutrients in agriculture. Soil Science Society of America, Madison, USA, pp. 371-425.

Mortvedt, J., Cunningham, H.G., 1971. Production, marketing, and use of other secondary and micronutrient fertilizer. In: Olson, R.A. (Ed.), Fertilizer technology and use. Soil Science Society of America, Madison, USA, pp. 413-454.

Mulder, E., 1954. Molybdenum in relation to growth of higher plants and micro-organisms. Plant and Soil 5, 368-415.

Nayyar, V., Randhawa, N., Pasricha, N., 1980. Effect of interaction between molybdenum and copper on the concentration of these nutrients in berseem and its yield. Indian Journal of Agricultural Sciences 50, 434-440.

Nieuwolt, S., Zaki, M. G., and Gopinathan, B. 1982. Agro-ecological regions in Peninsular Malaysia. MARDI, Serdang, Selangor, Malaysia. pp 22.

Noel, T., Sheng, C., Yost, C., Pharis, R., Hynes, M., 1996. Rhizobium leguminosarum as a plant growth-promoting rhizobacterium: direct growth promotion of canola and lettuce. Canadian Journal of Microbiology 42, 279-283.

Okuda, A., Yamaguchi, M., Nioh, I., 1962. Nitrogen-Fixing Microorganisms in Paddy Soils X: Effect of molybdenum on the growth and the nitrogen assimilation of Tolypothrix tenuis. Soil Science and Plant Nutrition 8, 35-39.

Paramananthan, S., 1978. Rice Soil of Malaysia. Rice and Soil. International Rice Research Institute, los Banos, Philippines.

Paramananthan, S., 1998. Malaysian soil taxonomy (second approximation): a proposal for the classification of Malaysian soils. Malaysian Society of Soil Science.

Paschinger, H. A changed nitrogenase activity in Rhodosdpirillum rubrum after substitution of tungsten for molubdenum. Arch. Microbiol. 101, 379-389.

Pasricha, N., Nayyar, V., Randhawa, N., Sinha, M., 1977. Influence of sulphur fertilization on suppression of molybdenum uptake by berseem (Trifolium alexandrinum L.) and oats (Avena sativa L.) grown on a molybdenumtoxic soil. Plant and Soil 46, 245-250.

Patrick Jr, W., 1981. The role of inorganic redox systems in controlling reduction in paddy soils. Proceedings of Symposium on Paddy Soils. Springer, pp. 107-117.

Paudyal, S., Aryal, R.R., Chauhan, S., Maheshwari, D., 2007. Effect of heavy metals on growth of Rhizobium strains and symbiotic efficiency of two species of tropical legumes. Scientific World 5, 27-32.

Pearsall, W., 1938. The Soil Complex in Relation to Plant Communities: III. Moorlands and Bogs. The Journal of Ecology, 298-315.

Phillips, R.L., Meyer, R.D., 1993. Molybdenum concentration of alfalfa in Kern County, California: 1950 versus 1985. Communications in Soil Science & Plant Analysis 24, 2725-2731.

Pitt, M., 1976. Molybdenum toxicity: interactions between copper, molybdenum and sulphate. Agents and Actions 6, 758-769.

Ponnamperuma, F., 1984. Effects of flooding on soils. Flooding and plant growth. Academic Press, INC, USA, pp. 9-45.

Ponnamperuma, F., 1985. Chemical kinetics of wetland rice soils relative to soil fertility. Wetland soils: characterization, classification and utilization. International Rice Research Institute, Los Banos, Philippines, pp. 71-89.

Radziah, O., Aminun Naher, U., Zuraidah Yusoff, S., 2013. Effect of urea-N on growth and indoleacetic acid production of Stenotrophomonas maltophilia (Sb16) isolated from rice growing soils in Malaysia. Chilean Journal of Agricultural Research 73, 187-192.

Razmjoo, K., Henderlong, P.R., 1997. Effect of potassium, sulfur, boron, and molybdenum fertilization on alfalfa production and herbage macronutrient contents. Journal of plant nutrition 20, 1681-1696.

Reddy, K.J., Gloss, S.P., 1993. Geochemical speciation as related to the mobility of F, Mo and Se in soil leachates. Applied geochemistry 8, 159-163.

Reddy, K.J., Munn, L.C., Wang, L., 1997. Chemistry and mineralogy of molybdenum in soils. Molybdenum in Agriculture, 4-22.

Redfern, S.K., Azzu, N., Binamira, J.S., 2012. Rice in Southeast Asia: facing risks and vulnerabilities to respond to climate change. Build Resilience Adapt Climate Change Agri Sector 23, 295.

Reisenauer, H., 1963. The effect of sulfur on the absorption and utilization of molybdenum by peas. Soil Science Society of America Journal 27, 553-555.

Revillas, J., Rodelas, B., Pozo, C., Martínez‐Toledo, M., González‐López, J., 2000. Production of B‐group vitamins by two Azotobacter strains with phenolic compounds as sole carbon source under diazotrophic and adiazotrophic conditions. Journal of Applied Microbiology 89, 486-493.

Richardson, A.E., 2001. Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. Functional Plant Biology 28, 897-906.

Rickard, D., Luther, G.W., 2007. Chemistry of iron sulfides. Chemical reviews 107, 514-562.

Robinson, D., LeLacheur, K., Brossard, G., 1957. Effect of molybdenum applications on leguminous hay crops in Prince Edward Island. Canadian Journal of Plant Science 37, 193-195.

Robinson, W., Alexander, L., 1953. Molybdenum content of soils. Soil Science 75, 287-292.

Romheld, V., Marscher, H., 1991. Functions of Micronutrients in Plants. In: Mortvedt, J., Giordano, P., Lindsay, W.L. (Eds.), Micronutrient in Agriculture. Soil Scinece Society of America, Madison, USA.

Roy, W., Hassett, J., Griffin, R., 1986. Competitive coefficients for the adsorption of arsenate, molybdate, and phosphate mixtures by soils. Soil Science Society of America Journal 50, 1176-1182.

Ryu, C. M., Farag, M. A., Hu, C. H., Reddy, M. S., Wei, H. X., Pare, P. W., Kloepper, J. W. 2003. Bacterial volatiles promote growth in Arabidopsis. Proceedings of the National Academy of Sciences of the USA, 100, 4927-4932.

Sauchelli, V., 1969. Trace elements in agriculture. Van Nostrand Reinhold, United States of America, New York.

Schwarz, G., Mendel, R.R., Ribbe, M.W., 2009. Molybdenum cofactors, enzymes and pathways. Nature 460, 839-847.

Scott, M.L., 1972. Trace Elements in Animal Nutirition. In: Mortvedt, J., Giordano, P., Lindsay, W.L. (Eds.), Micronutrients in Agriculture. Soil Science Society of America, Madison, USA, pp. 555-591.

Seefeldt, L.C., Hoffman, B.M., Dean, D.R., 2009. Mechanism of Mo-dependent nitrogenase. Annual review of biochemistry 78, 701.

Seefeldt, L.C., Yang, Z.-Y., Duval, S., Dean, D.R., 2013. Nitrogenase reduction of carbon-containing compounds. Biochimica et Biophysica Acta (BBA)-Bioenergetics 1827, 1102-1111.

Shah, V.K., Ugalde, R.A., Imperial, J., Brill, W.J., 1984. Molybdenum in nitrogenase. Annual review of biochemistry 53, 231-257.

Shamshuddin, J., 2014a. Acid sulfate soils: occurance, properties and utilisation for rice. Akademic Science Malaysia, FCA's, Malaysia.

Shamshuddin, J., Elisa Azura, A., Shazana, M.A.R.S., Fauziah, C.I., Panhwar, Q.A., Naher, U.A., 2014b. Properties and Management of Acid Sulfate Soils in Southeast Asia for Sustainable Cultivation of Rice, Oil Palm, and Cocoa. Advances in Agronomy. 124, 91-142.

Shivashankar, K., Hagstrom, G., 1991. Molybdenum Fertilizer Sources and Their use in crop production. In: Portch, S. (Ed.), Proceedings of the International Symposium on the Role of Sulphur, Magnesium and Micronutrients in Balanced Plant Nutrition. Sulfur Institute, Washington DC, pp. 297-305.

Shukla, P., Pathak, A., 1973. Effect of Molybdenum, Phosphorus and Sulphur on the Yield and Composition of Berseem in Acid Soil. Journal of the Indian Society of Soil Science 21, 187-192.

Sims, J., Atkinson, W., 1976. Lime, molybdenum, and nitrogen source effects on yield and selected chemical components of burley tobacco. Tobacco Sicience. 20, 8.

Sims, J., Atkinson, W., Smitobol, C., 1975. Mo and N effects on growth, yield, and Mo composition of burley tobacco. Agronomy Journal 67, 824-828.

Sims, J., Leggett, J., Pal, U., 1979. Molybdenum and sulfur interaction effects on growth, yield, and selected chemical constituents of burley tobacco. Agronomy Journal 71, 75-78.

Singh, B., Khandelwal, R., Singh, B., 1992. Effects of manganese and molybdenum fertilization with Rhizobium inoculation on the yield and protein content of cowpea. Journal of the Indian Society of Soil Science 40, 738-741.

Singh, M., Kumar, V., 1979. Sulfur, phosphorus, and molybdenum interactions on the concentration and uptake of molybdenum in soybean plants (Glycine max). Soil Science 127, 307-312.

Škarpa, P., Kunzova, E., Zukalova, H., 2013. Foliar fertilization with molybdenum in sunflower (Helianthus annuus L.). Plant Soil Environ 59, 156-161.

Smoleń, S., 2012. Foliar Nutrition: Current State of Knowledge and Opportunities. Advances in Citrus Nutrition. Springer, pp. 41-58.

Solaiman, A.R.M., 1999. Effect of Bradyrhizobium japanicum inoculation and molybdenum on soybean. Bangladesh Journal of Botany 28, 181-183.

Song, J., Zhao, F.J., McGrath, S.P., Luo, Y.M., 2006. Influence of soil properties and aging on arsenic phytotoxicity. Environmental Toxicology and Chemistry 25, 1663-1670.

Spanos, N., Vordonis, L., Kordulis, C., Lycourghiotis, A., 1990. Molybdenum-oxo species deposited on alumina by adsorption: I. Mechanism of the Adsorption. Journal of Catalysis 124, 301-314.

Srivastava, A., Singh, S., 2003. Foliar fertilization in citrus–A review. Agricultural Reviews 24, 250-264.

Steiner, F., Zoz, T., 2015. Foliar application of molybdenum improves nitrogen uptake and yield of sunflower. African Journal of Agricultural Research 10, 1923-1928.

Stout, P., Meagher, W., Pearson, G., Johnson, C., 1951. Molybdenum nutrition of crop plants. Plant and Soil 3, 51-87.

Talibudeenm, O., 1981. Cation exchange in soils. In: Greenland, D.J., Hayes, M.H.B. (Eds.), The Chemistry of Soil Processes. Willey, Chichester, UK, pp. 115-117.

Tanner, P., 1978. A relationship between premature sprouting on the cob and the molybdenum and nitrogen status of maize grain. Plant and Soil 49, 427-432.

Thompson, M., Zao, L., 1985. Rapid determination of molybdenum in soils, sediments and rocks by solvent extraction with inductively coupled plasma atomic-emission spectrometry. Analyst 110, 229-235.

Timmer, C.P., Block, S., Dawe, D., 2010. Long-run dynamics of rice consumption, 1960-2050. Rice in the global economy: strategic research and policy issues for food security 2010139.

Tomatsu, H., Takano, J., Takahashi, H., Watanabe-Takahashi, A., Shibagaki, N., Fujiwara, T., 2007. An Arabidopsis thaliana high-affinity molybdate transporter required for efficient uptake of molybdate from soil. Proceedings of the National Academy of Sciences 104, 18807-18812.

Underwood, E., 2012. Trace Elements in Human and Animal Nutrition. Elsevier.

Valenciano, J., Marcelo, V., Miguelez-Frade, M., 2011. Effect of different times and techniques of molybdenum applicationon chickpea (Cicer arietinum) growth and yield. Spanish Journal of Agricultural Research 9, 1271-1278.

Van der Weijden, C.H., Middelburg, J.J., De Lange, G.J., Van der Sloot, H.A., Hoede, D., Woittiez, J.R., 1990. Profiles of the redox-sensitive trace elements As, Sb, V, Mo and U in the Tyro and Bannock Basins (eastern Mediterranean). Marine Chemistry 31, 171-186.

Vieira, R., Cardoso, E., Vieira, C., Cassini, S., 1998. Foliar application of molybdenum in common beans. I. Nitrogenase and reductase activities in a soil of high fertility. Journal of Plant nutrition 21, 169-180.

Vieira, R., Salgado, L., Ferreira, A.d.B., 2005. Performance of common bean using seeds harvested from plants fertilized with high rates of molybdenum. Journal of plant nutrition 28, 363-377.

Villora, G., Moreno, D.A., Romero, L., 2003. Potassium supply influences molybdenum, nitrate, and nitrate reductase activity in eggplant. Journal of Plant Nutrition 26, 659-669.

Volkmar, K. M., & Bremer, E. 1998. Effects of seed inoculation with a strain of Pseudomonas fluorescens on root growth and activity of wheat in well-watered and drought-stressed glass-fronted rhizotrons. Canadian Journal of Plant Sciences, 78, 545-551.

Wallace, A., Romney, E., Alexander, G., Kinnear, J., 1977. Phytotoxicity and some interactions of the essential trace metals iron, manganese, molybdenum, zinc, copper, and boron. Communications in Soil Science & Plant Analysis 8, 741-750.

Wang, D., Aller, R.C., Sañudo-Wilhelmy, S.A., 2011. Redox speciation and early diagenetic behavior of dissolved molybdenum in sulfidic muds. Marine Chemistry 125, 101-107.

Weng, B.-Q., Huang, D.-F., Xiong, D.-Z., Wang, Y.-X., Luo, T., Ying, Z.-Y., Wang, H.-P., 2009. Effects of molybdenum application on plant growth, molybdoenzyme activity and mesophyll cell ultrastructure of round leaf cassia in red soil. Journal of Plant Nutrition 32, 1941-1955.

Wichard, T., Mishra, B., Myneni, S.C., Bellenger, J.-P., Kraepiel, A.M., 2009. Storage and bioavailability of molybdenum in soils increased by organic matter complexation. Nature Geoscience 2, 625-629.

Williams, C., Maier, N., Bartlett, L., 2005. Effect of molybdenum foliar sprays on yield, berry size, seed formation, and petiolar nutrient composition of "Merlot" grapevines. Journal of Plant Nutrition 27, 1891-1916.

Williams, I., H, 1971a. Molybdenum Deficiency. UK Ministry of Agriculture, Fisheries and Food, United Kingdom.

Williams, I.H., 1971b. Molybdenum Deficiency. UK Ministry of Agriculture, Fisheries and Food, United Kingdom.

Wilson, R., 1949. Molybdenum in relation to the scald disease of beans. Australian Journal of Science 11, 209-211.

Witty, J.F., 1979. Acetylene eduction assay can overstimate nitrogen-fixation in Soil. Soil Biology and Biochemistry 11, 209-210.

Wolfe, M., 1954. The effect of molybdenum upon the nitrogen metabolism of Anabaena cylindrica I. A study of the molybdenum requirement for nitrogen fixation and for nitrate and ammonia assimilation. Annals of Botany 18, 299-308.

Wu, C.-H., Lo, S.-L., Lin, C.-F., 2000. Competitive adsorption of molybdate, chromate, sulfate, selenate, and selenite on γ-$Al_2 O_3$. Colloids and Surfaces A: Physicochemical and Engineering Aspects 166, 251-259.

Xie, R., MacKenzie, A., 1991. Molybdate sorption-desorption in soils treated with phosphate. Geoderma 48, 321-333.

Yamane, I., 1978. Electrochemical in rice soils. Soil and Rice. International Rice Research Institute, Los Banos, Philippines, pp. 381-399.

Yoshida, S., Ferno, D.A., Cock, J.H., Gomez, K.A. 1976. Laboratory manual for physiological studeis of rice. International Rice Reasearch Institute, Los Banos Philippines, pp: 83.

Younge, O.R., Takahashi, M., 1953. Response of alfalfa to molybdenum in Hawaii. Agronomy Journal 45, 420-428.

Yu, M., Hu, C., Wang, Y., 1999. Influences of seed molybdenum and molybdenum application on nitrate reductase activity, shoot dry matter, and grain yields of winter wheat cultivars. Journal of Plant Nutrition 22, 1433-1441.

Zaharah, A., Bah, A., Mwange, N., Kathuli, P., Juma, P., 1999. Management of gliricidia (Gliricidia sepium) residues for improved sweet corn yield in an Ultisol. Nutrient Cycling in Agroecosystems 54, 31-39.

Zakikhani, H., Ardakani, M.R., Rejali, F., Gholamhoseini, M., Joghan, A.K., Dolatabadian, A., 2012. Influence of Diazotrophic Bacteria on Antioxidant Enzymes and Some Biochemical Characteristics of Soybean Subjected to Water Stress. Journal of Integrative Agriculture 11, 1828-1835.

Zakikhani, H., Yusop, M., Anuar, A., Radziah, O., Soltangheisi, A., 2014. Effects of Different Levels of Molybdenum on Uptake of Nutrients in Rice Cultivars. *Asian Journal of Crop Science* 6, 236-244.

Zoz, T., Steiner, F., Testa, J.V.P., Seidel, E.P., Fey, R., Castagnara, D.D., Zoz, A., 2012. Foliar fertilization with molybdenum in wheat. Semina: Ciências Agrárias 33, 633-638.