UNIVERSITI PUTRA MALAYSIA

IMPROVEMENT OF ACID SOILS AND RICE (Oryza sativa L.) PRODUCTIVITY USING ORGANIC AMENDMENTS FROM ORGANIC WASTES

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By

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

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy

IMPROVEMENT OF ACID SOILS AND RICE (*Oryza sativa* L.) PRODUCTIVITY USING ORGANIC AMENDMENTS FROM ORGANIC WASTES

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June 2019

Chairman : Prof. Ahmed Osumanu Haruna, PhD
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Rice productivity on tropical soils is very low partly because most of these soils are acidic due to high amounts of Fe and Al which limit rice growth and development, soil nutrients availability, fertilizer use efficiency, and yield. This low rice yield prompted a need to substitute some amount of chemical fertilizers with organic amendments from organic wastes. The general objective was to increase soil physico-chemical properties, rice growth variables, nutrients use efficiency, and rice productivity using organic amendments from organic wastes *leucaena leucocephala* (tropical and subtropical leguminous plants locally called Petai Belalang), chicken manure, cow dung, forest litter, and chicken litter biochar were co-composted using standard procedures to improve the quality and nutrients content. The study was conducted at Universiti Putra Malaysia Bintulu Campus and transformed wastes were evaluated in a pot study using standard procedures after which potential organic amendments were selected for field and ammonia volatilization studies.

The selected treatments were: (i) Soil only (T1), (ii) Existing recommended fertilization (T2), (iii) Biochar-forest litter compost (T3), (iv) Biochar-chicken litter compost (T4), (v) Biochar-cow dung compost (T5), (vi) Biochar-*leucaena leucocephala* compost (T6), and (vii) Biochar-*leucaena leucocephala* - chicken litter compost (T7). Three replicates of each treatments in composting, pot study, ammonia volatilization was arranged using Randomized Complete Design. In the field study, four replicates of each treatments arranged using Randomized Complete Block Design were evaluated in first, second, and third planting cycles and thereafter, rice grain quality was determine using dielectric analysis whereas soil physico-chemical properties characterization, soil ammonia loss estimation, plants growth variables, plants nutrients use efficiency, and economic viability of using the soil organic amendments in rice cultivation were determined using standard procedures.

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Treatments with *L. leucocephala* showed higher decomposition because of lower C:N ratio over chicken manure, cow dung, and forest litter. Percentage humic acids in forest litter was significantly higher than those of *L. leucocephala*, chicken manure, and cow dung, however, the functional groups of the humic acids from animal manures were higher than those extracted from plants. Co-application of chicken litter biochar increased the nutrient elements of *L. leucocephala*, forest litter, chicken manure, and cow dung but reduced compost temperature, composting period, compost humic acids content, and functional groups of the humic acids. Results in pot, ammonia volatilization, and field studies revealed that organic amendments significantly reduced soil acidity especially Fe and Al whereas soil pH, total carbon, and nutrients availability were significantly increased compared soils of the conventional method.

The study on ammonia volatilization revealed that ammonia emission from urea was higher with *L. leucocephala* than those with forest litter, chicken manure, and cow dung. In a field study, the organic amendments improved plant nutrients use efficiency, rice growth variables, and grain yield compared with the existing method of cultivating rice. The co-composted chicken litter biochar improved rice grain yields in the first (9 to 11 t ha^{-1}), second (11 to 13 t ha^{-1}), and third (8 to 10 t ha^{-1}) planting cycles. Inorganic N, P, K, MgO, and trace element fertilizers use were reduced in soils with organic amendments by 25%, 100%, 64%, 100%, and 100%, respectively whereas maturity of rice was also reduced by 20 days over the conventional methods.

Although production cost using the new intervention increased by 36.27% over the conventional method in the first and second planting cycles, it reduced by 19.87% in the third planting cycle. Net revenue in the new intervention increased over the conventional method ranging from 248.53% to 662.48% in first, second, and third planting cycles respectively whilst maintaining the quality of rice grains. Among the organic amendments used chicken litter biochar co-composted with *L. leucocephala* and chicken manure treatment was more profitable for growing MR219 compared with those composted with forest litter, poultry, and cow dung. Hence, it is recommended that small scale rice farmers should be trained on converting their agriculture wastes into organic amendments for detoxifying acidic soils to improve rice productivity.

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

PENINGKATAN ACID TANAH DAN PADI (*Oryza sativa* L.) PRODUKTIVITI MENGGUNAKAN PINDAAN ORGANIK DARI BUANGAN ORGANIK

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Pengerusi: **Prof. Ahmed Osumanu Haruna, PhD**
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Produktiviti padi di tanah tropika adalah sangat rendah sebahagiannya kerana kebanyakan tanah ini adalah berasid disebabkan oleh jumlah Fe dan Al yang tinggi yang menghadkan pertumbuhan dan pembangunan padi, ketersediaan nutrien tanah, kecekapan penggunaan baja, dan hasil. Hasil padi yang rendah ini menjurus kepada perlunya untuk menggantikan sejumlah baja kimia dengan bahan pembaikpulih organik daripada sisa organik. Objektif umum adalah untuk meningkatkan sifat fiziko-kimia tanah, pembolehubah pertumbuhan padi, kecekapan penggunaan nutrien dan produktiviti padi menggunakan bahan pembaikpulih organik daripada sisa organik yang terdiri daripada *Leucaena leucocephala* (tumbuhan kekacang tropika dan subtropika tempatan dipanggil Petai Belalang), tahi ayam, tahi lembu, daun luruhan hutan, dan biochar tahi ayam yang dikomposkan bersama menggunakan prosedur piawai untuk memperbaiki kualiti dan kandungan nutrient. Kajian ini telah dijalankan di Universiti Putra Malaysia Kampus Bintulu dan bahan buangan yang ditansformasikan telah dinilai di dalam kajian pasu menggunakan prosedur piawai yang mana selepas itu bahan pembaikpulih organik yang berpotensi telah dipilih untuk kajian lapangan dan kajian pemeruapan ammonia.

Rawatan yang telah dipilih adalah: (i) Tanah sahaja (T1), (ii) Syor pembajaaan sedia adan (T2), (iii) Kompos biochar –daun luruhan hutan (T3), (iv) Kompos biochar-tahi ayam (T4), (v) Kompos biochar – tahi lembu (T5), (vi) Kompos biochar - *leucaena leucocephala* (T6), dan (vii) Kompos biochar - *leucaena leucocephala* – tahi ayam (T7). Tiga replikasi bagi setiap rawatan untuk pengkomposan, kajian pasu,dan pemeruapan ammonia telah diatur menggunakan Rekabentuk Rawak Lengkap. Dalam kajian lapangan, empat replikasi bagi setiap rawatan yang telah disusun menggunakan Rekabentuk Blok Rawak Lengkap Rambang telah dinilai di dalam kitaran penanaman pertama, kedua, dan ketiga dan selepas itu, kualiti beras telah ditentukan menggunakan analisis dielektrik manakala pencirian sifat fiziko-kimia tanah, anggaran kehilangan ammonia , pembolehubah pertumbuhan tanaman, kecekapan penggunaan nutrient tanaman , dan daya maju ekonomi menggunakan bahan pembaikpulih tanah organik dalam penanaman padi telah ditentukan dengan menggunakan prosedur piawai.

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Rawatan dengan *L. leucocephala* menunjukkan penguraian lebih tinggi kerana nisbah C:N yang lebih rendah berbanding tahi ayam, tahi lembu, dan daun luruhan hutan. Peratusan asid humik dalam daun luruhan hutan adalah lebih tinggi dengan bererti daripada *L. leucocephala,* tahi ayam dan tahi lembu, walaubagaimanapun, kumpulan berfungsi asid humik daripada najis haiwan adalah lebih tinggi daripada yang diekstrak daripada tanaman. Aplikasi-bersama biochar –tahi ayam meningkatkan unsur-unsur nutrien dalam *L. leucocephala*, daun luruhan hutan, petai, tahi ayam dan tahi lembu tetapi mengurangkan suhu kompos, tempoh pengkomposan, kandungan asid humik di dalam kompos, dan kumpulan berfungsi asid humik. Keputusan dalam pasu, kajian pemeruapan ammonia, dan kajian lapangan menunjukkan bahawa bahan pembaikpuih organik mengurangkan keasidan tanah terutamanya Fe dan Al manakala pH tanah, jumlah karbon, dan ketersediaan nutrien telah meningkat dengan bererti berbanding tanah secara kaedah konvensional. Kajian ke atas pemeruapan ammonia mendedahkan bahawa pelepasan ammonia dari urea adalah lebih tinggi dengan *L. leucocephala* berbanding dengan daun luruhan hutan, tahi ayam dan tahi lembu.

Dalam satu kajian lapangan, bahan pembaikpulih organik telah menambahbaik kecekapan penggunaan nutrient tanaman, pembolehubah pertumbuhan padi, dan hasil bijirin berbanding kaedah penanaman padi sedia ada. Kompos - bersama tahi ayam dan biochar menambahbaik hasil bijirin pada kitaran penanaman pertama (9 hingga 11 t ha^{-1}), kedua (11 hingga 13 t ha^{-1}), dan ketiga (8 hingga 10 t ha^{-1}). Penggunaan N, P, K, MgO, dan unsur surih baja bukan organik telah dikurangkan dalam tanah dengan bahan pembaikpulih organik masing – masing sebanyak 25%, 100%, 64%, 100%, dan 100% manakala tempoh kematangan beras juga dikurangkan sebanyak 20 hari berbanding kaedah konvensional. Walaupun kos pengeluaran menggunakan intervensi baru meningkat sebanyak 36.27% berbanding kaedah konvensional dalam kitaran penanaman pertama dan kedua, tetapi ia menurun sebanyak 19.87% dalam kitaran penanaman ketiga. Hasil bersih dalam intervensi baru telah meningkat berbanding kaedah konvensional berjulat daripada 248.53% kepada 662.48% pada kitaran penanaman pertama, kedua, dan ketiga dan pada masa yang sama mengekalkan kualiti beras. Antara bahan pembaikpulih organik yang digunakan biochar tahi ayam yang dikomposkan bersama *L. leucocephala* dan rawatan tahi ayam adalah lebih menguntungkan untuk menanam MR219 berbanding dengan kompos daun luruhan hutan, poltri, dan tahi lembu. Justeru itu, adalah disyorkan petani skala kecil perlu dilatih untuk menukar sisa pertanian mereka kepada bahan pembaikpulih organik untuk detoksifikasi tanah berasid bagi meningkatkan produktiviti padi

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirements for the degree of Doctor of Philosophy. The members of the supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
AC	Alternating current
AE_N	Agronomic Efficiency of the applied N
Al	Aluminium
Al:Ca	Aluminium per calcium
ANOVA	Analysis of variance
C	Carbon
C:N	Carbon per nitrogen
CEC	Cation exchange capacity
CRD	Complete Randomized Design
DC	Direct current
DMY	Dry matter yield
EPA	Environmental Protection Agency
ID	Internal diameter
K	Potassium
KCl	Potassium chloride
K_{up}	Potassium uptake
LCR	Inductance-capacitance-resistance
MADA	Muda Agricultural Development Authority
MgO	Magnesium oxide
MOP	Muriate of potash
N	Nitrogen
Na	Sodium
NH_4^+	Ammonium ions
NO_3^-	Nitrate
N_{up}	Nitrogen uptake
OM	Organic matter
P	Phosphorous
P_{up}	Phosphorus uptake
RC	Research Complex
RDW	Root dry weight
RE_N	Crop Recovery of applied N
TDR	Time domain reflectometry
TOM	Total organic matter
TSP	Triple superphosphate
UAN	Urea-ammonium nitrate
UNESCO	United Nations Organization for Education, Science and Culture
US	United State

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CHAPTER 1

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most consumed grain crops in the world although it requires significant fertilization for optimum yield (IRRI, 2006; Linquist *et al*., 2015). The consumption of fertilizers is even higher in the tropics because of poor soil fertility (Hashemi *et al*., 2015). Tropical acid soils are less fertile because they are highly weathered due to relatively high temperature and rainfall thus, resulting in the high amount of Fe and Al (Brady and Weil, 2008; Paz *et al*., 2016). Additionally, leaching of basic cations such as Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} (Lu *et al*., 2015) makes the soil more acidic and difficult for most agronomic crops to extend their roots to subsoil (Blumenschein, 2016). As a result, most farmers tend to use higher amounts of chemical fertilizers which does not only increase cost production of rice, but it also pollutes the environment besides reducing rice grain quality (Yadav *et al*., 2013; Gupta *et al*., 2015). Despite higher chemical fertilizer application, rice yield in Malaysia is approximately 4 to 5 t ha^{-1} (MADA, 2015), a yield that makes rice production an expensive venture as productivity per worker involved is very low (FAO, 2002).

Commercial Malaysian Indica rice variety, MR 219 developed by the Malaysian Agricultural Research and Development Institute (MARDI) based on a direct seeding planting system (Alias 2002) has been classified as high-yielding rice producing more than 10 t ha^{-1}. The panicle of MR219 and grain weight can be as high 200 g $panicle^{-1}$ and 28–30 mg, respectively. Additionally, MR219 has maturation period of 105–111 days, tall but strong culms, and resistance to blast and bacterial leaf blight thereby increasing its local popularity. The productivity of MR 219 can be further improved in many ways and in this study, the soil health and its nutrient content were explored. A recent study involving the cultivation of MR219 on Ultisols using 5 t ha^{-1} chicken litter biochar, 75% of recommended N (212 kg ha^{-1} urea), and 35% recommended K (41 kg ha^{-1} muriate of potash) yielded rice grain yield at 8.31 t ha^{-1} (Maru *et al*., 2015; MADA, 2015). This is because biochar as soil organic amendment increased the soil physical and chemical properties, increased plants nutrients use efficiency, and rice yield (Brady and Weil, 2008; Maru *et al*., 2015). Therefore, the use of biochar as a soil amendment is innovative and highly a promising practice for sustainable agriculture (Renner, 2007). However, this approach has not increased rice yield of Malaysia to its potential of 10 t ha^{-1}. This was because of low nutrients release by the chicken litter biochar for the hybrid rice plant. Hence there was the need to enhance the quality and nutrients content of the soil organic amendments using organic wastes to increase rice productivity.

The government of Malaysia is also promoting programs that encourage recycling and use of agricultural wastes such as empty oil-palm fruit bunches (EFB), chicken litter, cow dung, rice straw, rice husk, and other agro-industrial wastes (Faridah, 2001). Innovations such as pyrolysis of biomass into biochar and composting are mostly adopted in the recycling of these agricultural wastes. In Malaysia, the most common practice is composting which is a natural and deliberate biological reduction of organic wastes under controlled, that is, aerobic conditioning of wastes into a stable product called humus (Saveyn and Eder, 2014). Therefore, in this study, animal manures and

plant residues such as cow dung, poultry manure, *L. leucocephala*, and forest litter were used to improve quality and nutrients content of chicken litter biochar. It is not possible to assign a general percentage of nutrients that can be found in manures because plant nutrient levels in manures vary with animal type, age, ration, and feed consumption, amount of dilution of wastewater, runoff entering the manure storage facility, storage method, and time of storage (Manyi-Loh *et al*., 2016).

For plant residues, leaves of *L. leucocephala* are highly nutritious and can produce dry matter yield of 3 to 30 t ha^{-1} $year^{-1}$ (Ghosh *et al*., 2017). Bala *et al*. (2003) showed that total N and P contents of *L. leucocephala* were 4.2% and 0.23% respectively, making it a favourable plant residue to use in this study. Another accessible plant material is forest litterfall and Malaysia's total forest area is about 20.5 million ha (Keenan *et al*., 2015) with an estimated annual litterfall of approximately 80 to 129 million ton ha^{-1}. However, there is limited information on litter uses for agriculture compared with leguminous trees such as *L. leucocephala* and some commonly used animal waste such as chicken litter and cow dung. Hence, there was the need to determine the potentials of using forest litter as soil organic amendment for rice productivity in comparison to those of cow dung, chicken, and *L. leucocephala*.

1.1 Research questions

1. Can cost of using chicken litter biochar in rice production be further reduced whilst reducing the use of chemical fertilizer and increasing rice yield?
2. Can quality and nutrients content of co-composted chicken litter biochar with organic wastes be increased to improve soil physico-chemical properties, fertilizer use efficiency, and rice productivity?
3. Do different soil organic amendments affect the quality of rice grain?

1.2 Hypothesis

H_A: Co-composted biochar with agriculture wastes will increase the volume and nutrients content of organic amendments which will improve soil physico-chemical properties and rice productivity on tropical acid soils

1.3 General objective

General objective of this study was to improve soil physico-chemical properties, rice growth variables, nutrients use efficiency, and rice productivity of tropical acid soil using organic amendments from organic wastes

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