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EVALUATION OF ENHANCED EFFICIENT FERTILIZER UREA ON RICE PRODUCTION AND ENVIRONMENT

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By

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EVALUATION OF ENHANCED EFFICIENT FERTILIZER UREA ON RICE PRODUCTION AND ENVIRONMENT

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The use of enhanced efficiency fertilizer (EEF) urea as an alternative for the conventional urea fertilizer is one of the main strategies to improve nitrogen use efficiency (NUE) in rice cultivation. The production of affordable EEF with good quality could increase its consumption by farmers. The objectives of this study were to evaluate the efficiency of the selected urea EEF in enhancing NUE, reducing gaseous N emission and improving rice productivity.

Three groups of EEF were used; biochar impregnated urea (BIU) comprising of BIU 300-5, BIU 300-10, BIU 700-5, and BIU 700-10; geopolymer coated urea (GCU) comprising of single layer geopolymer coating (UG1), double layer coating (UG2), and single layer starch-modified geopolymer (SG1); and palm stearin coated urea (PSCU) with inhibitors comprising of PS, PS+DMPP-50, PS+DMPP-100, PS+DMPP-150, PS+Cu, and PS+Zn.

Isotopic study using 15N was carried out to determine the timing of N uptake by rice as a guideline for EEF development. Rice removed N until 11th week after transplanting and the NUE was about 57% under common practices. Nitrogen derived from fertilizer (NDFF) were 22-40% in straw, 18.7-29.3% on root, and 26.4-27.8% in grain.

Laboratory study of the selected EEF was carried out to determine the N transformation, ammonia (NH_3) volatilization loss and nitrous oxide (N_2O) emission on Selangor soil and Chempaka soil. Both GCU and PSCU retained substantial amount of urea-N in soil after 2 weeks of application. Application of EEF resulted in higher N recovery after 4 weeks by 4.6-17.6%. The use of EEF also resulted in the reduction of NH_3 loss as by 26-30% in BIU, 11-19% in GCU, and 16-35% in PSCU, while N_2O emission was reduced by 15.0-49.8%.

In a pot study under glasshouse condition, rice were planted with isotopic 15N was used to determine the fertilizer-N uptake by rice. The application of EEF resulted in yield increment by 19-106% in Selangor soil and 10-37% in Chempaka soil. The application of EEF also reduced ammonia volatilization loss by 31-77% on Selangor soil and 21-56% on Chempaka soil, while N_2O emission flux was reduced by 52.7-100.0% on both soil series. Fertilizer-N uptake was improved by EEF treatments by 28-140%.

A field trial was carried out in Sungai Besar to evaluate the efficacy of EEF on rice production and N uptake under field condition using BIU and PSCU EEF. Application of EEF had significantly improved height, SPAD values (chlorophyll content) and harvest index of rice plants. The EEF treatments also improved grain yield by 5-20% and N uptake by 12.2-35.6% compared to urea.

In conclusion, EEF application improved NUE, reduced gaseous N emission and increased rice production compared to the conventional urea.

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

PENILAIAN BAJA UREA YANG DIPERTINGKATKAN KECEKAPAN KE ATAS PRODUKTIVITI PADI DAN ALAM SEKITAR

Oleh

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Penggunaan baja urea yang dipertingkatkan kecekapan (EEF) sebagai alternatif kepada baja urea konvensional merupakan suatu strategi utama dalam meningkatkan kecekapan penggunaan nitrogen dalam penanaman padi. Penghasilan baja EEF yang mampu milik dan berkualiti mampu meningkatkan penggunaannya oleh petani. Objektif kajian ini adalah untuk menguji kecekapan urea EEF dalam meningkatkan kecekapan penggunaan N, mengurangkan pembebasan gas, dan meningkatkan produktiviti pangeluaran padi.

Tiga kumpulan EEF telah diuji; biochar impregnated urea (BIU) dengan 4 jenis EEF iaitu BIU 300-5, BIU 300-10, BIU 700-5, and BIU 700-10; geopolymer coated urea (GCU) dengan 3 jenis EEF iaitu single layer geopolymer coating (UG1), double layer coating (UG2), dan single layer starch-modified geopolymer (SG); dan palm stearin coated urea (PSCU) yang terdiri daripada PS, PS+DMPP-50, PS+DMPP-100, PS+DMPP-150, PS+Cu, and PS+Zn.

Kajian menggunakan isotop telah dijalankan untuk menentukan masa pengambilan N oleh padi. Daripada kajian ini, pokok padi hanya menyerap N sehingga minggu ke 11 selepas ditanam dan kadar kecekapan N adalah sekitar 57% sahaja. Nitrogen yang diperoleh daripada baja (NDFF) adalah sebanyak 22-40% dalam batang, 18.7-29.3% dalam akar dan 26.4-27.8% dalam biji padi.

Kajian makmal untuk EEF terpilih telah dijalankan untuk menentukan proses transformasi N, kadar kehilangan NH_3, dan pembebasan N_2O pada siri tanah Selangor dan Chempaka. Baja GCU dan PSCU telah mengekalkan sebahagian urea-N dalam tanah selepas 2 minggu ditabur. Penggunaan EEF telah mengekalkan N yang lebih tinggi selepas 4 minggu sebanyak 4.6-17.6%.,

mengurangkan kehilangan NH_3 sebanyak 11-35% dan mengurangkan pembebasan N_2O sebanyak 15.0-49.8% berbanding urea.
Untuk kajian rumah kaca, padi telah ditanam dengan isotop 15N digunakan untuk menentukan pengambilan N-baja oleh padi. Daripada kajian ini, penggunaan EEF telah meningkatkan hasil padi sebanyak 19-106% pada tanah Selangor dan sebanyak 10-37% pada tanah Chempaka. Penggunaan baja EEF juga telah mengurangkan pelepasan gas NH_3 sebanyak 31-77% pada tanah Selangor dan 21-56% pada tanah Chempaka, manakala pelepasan gas N_2O pula telah dikurangkan sebanyak 52.7-100.0% untuk kedua-dua jenis tanah. Pengambilan N-baja pula telah ditingkatkan sebanyak 28-140%.

Kajian lapangan telah dijalankan di Sungai Besar untuk menguji keberkesanan EEF ke atas produktiviti padi dan pengambilan N dalam keadaan sawah padi menggunakan baja EEF BIU dan PSCU. Penggunaan baja EEF telah meningkatkan ketinggian pokok padi, nilai SPAD (kandungan klorofil) dan index penuaian (HI) padi. Baja EEF yang digunakan juga meningkatkan hasil padi pada kadar 5-20% dan pengambilan N oleh pokok sebanyak 12.2-35.6% berbanding urea.

Sebagai kesimpulan, penggunaan baja EEF telah meningkatkan NUE, mengurangkan pelepasan gas N, serta meningkatkan penghasilan padi berbanding urea konvensional.

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I certify that a Thesis Examination Committee has met on 14 November 2016 to conduct the final examination of Mohammad Mu'az bin Hashim on his thesis entitled "Evaluation of Enhanced Efficient Fertilizer Urea on Rice Production and Environment" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

AAPFCO	Association of American Plant Food Control Officials
AEC	Anion exchange capacity
ANOVA	Analysis of variance
BIU	Biochar Impregnated Urea
CEC	Cation exchange capacity
CRD	Complete Randomized Design
DAT	Day after transplanting
DCD	Dicyandiamide
DMPP	3,4-Dimethylpirazole phosphate
DMRT	Duncan's Multiple Range Test
DOA	Malaysian Department of Agriculture
EEF	Enhanced Efficiency Fertilizer
FAO	Food and Agriculture Organization of the United Nations
GCU	Geopolymer Coated Urea
GHG	Greenhouse gases
GWP	Global warming potential
HI	Harvest index
IAEA	International Atomic Energy Agency
IPNI	International Plant Nutrient Institute
IRRI	International Rice Research Institute
MARDI	Malaysian Agricultural Research and Development Institute
MNA	Malaysian Nuclear Agency
NDFF	Nitrogen derived from fertilizer
NDFS	Nitrogen derived from soil
NI	Nitrification inhibitors
NUE	Nitrogen use efficiency
PSCU	Palm Stearin Coated Urea
SAS	Statistical Analysis System
SPAD	Soil Plant Analysis Development
SEM	Scanning electron microscope
SSL	Self-sufficiency level
TVA	Tennessee Valley Authority
UI	Urease inhibitors
UTeM	Universiti Teknikal Malaysia Melaka (Technical University of Malaysia Malacca)
UTP	Universiti Teknologi Petronas (Petronas Technology University)

CHAPTER 1

INTRODUCTION

1.1 Background information

As a nation that heavily dependent on rice as staple food, the requirement for optimum rice production is becoming more important in Malaysia. With the current population of 31 million and projected to grow, the demands of rice will exponentially increase. The optimum rice production will not only provide sufficient supply of food for the country but also essential in providing food security.

However, the efforts to improve rice production in Malaysia always appeared to be restrained. Even though rice varieties with excellent characteristics were cultivated, the national production remained stagnant. One of the possible reasons for this situation is low nitrogen (N) use efficiency (NUE) in rice farming system, commonly due to high losses. As the most important nutrient for rice farming, low NUE will seriously affect the efforts to improve rice production.

Mikkelsen et al. (1995) described that large losses of N from rice soils from fertilizer application occur through nitrification-denitrification, mineralization-immobilization, ammonia volatilization, and loss through floodwater and leaching. The loss of N from fertilizer application could add up to reach 60%. There are several factors that could affect N loss, such as soil properties and fertilizer management practices (Choudhury and Kennedy, 2005; Jones et al., 2013).

The low NUE resulted from the high loss will not only cause an increment in cost and waste of input, but it also contributes to the environmental related problems, such as eutrophication, groundwater pollution, and global warming (Dalton and Brand-Hardy, 2003). The environmental related problems that were created from N inefficiency does not comply with the sustainable agriculture requirement which include environmental conservation as one of its main components.

Nitrogen management in flooded rice system needs different approaches compared to the common aerobic condition. Flooded rice soil differs physically, chemically and biologically from dry soil (Mikkelsen et al., 1995). Upon flooding, the oxygen exchange between atmosphere and soil/water system is reduced. The remaining oxygen used up by aerobic microbes, resulting the soil to be devoid of oxygen, except a thin layer of about 10 mm thick at soil-water interface (Mikkelsen et al., 1995).

Recently, 4R nutrient stewardship program was introduced to improve nutrient use efficiency. Using right fertilizer source, at the right rate, at the right time

and in the right place was the basic concept in this program (IFA, 2009). In a rice field with continuous submergence of the soil, specific N management needs to be practiced to improve its efficiency. One way to achieve this is by using enhanced efficiency fertilizer (EEF) for urea application.

Enhanced efficiency fertilizer is a fertilizer with agronomic, economic, and environmental benefits over the conventional fertilizer (Timilsena et al., 2014). The ultimate goals in using EEF for N fertilizer are to improve NUE and reduce N losses (Trenkel, 2010). Aside from improving NUE, EEF usage in agriculture also have the potential to reduce the detrimental impacts of fertilizer application to the environment (Hatfield and Venterea, 2014).

1.2 Problem statement

Even though EEF has been widely proven as the better alternative for common fertilizer, its application in agriculture is reported at only 1% from the global fertilizer consumption (Timilsena at al., 2014). Considering its benefits to the agriculture, the global EEF consumption is extremely low.

The main reason that prevents the use of EEF by the rice farmers is its high cost. The price of EEF in the market could be as high as 8 to 12 times more than the conventional fertilizer (Lammel, 2005). The high price of EEF is caused by the high production costs which involve complicated processes and uses of expensive materials (Trenkel, 2010). The use of expensive EEF will result in the increment of production costs for the farmers, discouraging them from widely using the EEF.

Due to this problem, economical EEF needs to be developed to increase its appeals to the rice farmers. Less expensive and environmental friendly materials could be used in the development of EEF to reduce its production costs. The use of industrial wastes, such as palm stearin, rubber wood sawdust, and fly ashes as materials for EEF development could potentially produce high quality and cost effective EEF.

Recently, several EEF urea have been developed in Malaysia to provide an alternative for the common urea fertilizer. Biochar impregnated urea (BIU) is an EEF urea developed through collaboration with Universiti Teknikal Malaysia Melaka (UTeM) by incorporating urea with biochar from rubber wood sawdust. Another type of EEF is geopolymer coated urea (GCU) that was developed as a collaborative effort with Universiti Teknologi Petronas (UTP) that encapsulated urea granules with geopolymer materials. The use of palm stearin as coating materials with the addition of inhibitors also being studied in developing palm stearin coated urea (PSCU). As the new EEF, the performances of these EEF need to be studied extensively before they can be recommended to the farmers. Therefore, this study is conducted to evaluate the performances of BIU, GCU, and PSCU EEF on rice production and N efficiency.

1.3 Research objectives

In general, the main purpose of this study is to evaluate the recently developed EEF urea for its efficiency in managing N in soil and improving rice production. Specifically, the objectives of this study are:

i. To determine the timing of N uptake and N utilization by rice from urea application using ^{15}N isotope
ii. To evaluate and compare the effects of selected EEF on N transformation, ammonia loss and nitrous oxide emission under flooded condition on selected Malaysian rice soils
iii. To evaluate the efficacy of selected EEF on rice production and N uptake

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BIODATA OF STUDENT

Mohammad Mu'az Hashim was born in 1988 in Sarawak, Malaysia. Raised in Selangor, he obtained his primary and secondary school in Selangor, before furthered his study in Malacca Matriculation College in 2006-2007. He then pursued his study at the Universiti Putra Malaysia in Bachelor of Agricultural Science under Malaysian government scholarship and graduated in 2011.

Due to a significantly better achievement during his bachelor degree study, he was offered to pursue his study directly in PhD level for a fast track program in Land Resource Management, also in Universiti Putra Malaysia under the scholarship from the Ministry of Higher Education of Malaysia. For the future, his ambition is to contribute to the society through agriculture. For him, agriculture is not just academic or future carrier, but a life-long commitment.

LIST OF PUBLICATIONS

Accepted and Published

Mohd Fairus Dimin, Se Sian-Meng, Azizah Shaaban, and Mohammad Mu'az Hashim. 2014. Urea impregnated biochar to minimize nutrients loss in paddy soils. International Journal of Automotive and Mechanical Engineering. 10: 2016-2024.

Mohammad Mu'az Hashim, Mohd Khanif Yusop, Radziah Othman, and Samsuri Abd. Wahid. 2015. Characterization of N uptake pattern by Malaysian rice MR219 at different growth stage using 15N isotope. Rice Science. 22(5): 250-254.

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