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EFFECT OF CHICKEN LITTER BIOCHAR ON PHOSPHORUS AVAILABILITY IN ACID SOIL AND YIELD OF Zea mays L.

AUDREY ANAK ASAP

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EFFECT OF CHICKEN LITTER BIOCHAR ON PHOSPHORUS AVAILABILITY IN ACID SOIL AND YIELD OF *Zea mays* L

By

AUDREY ANAK ASAP

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EFFECT OF CHICKEN LITTER BIOCHAR ON PHOSPHORUS AVAILABILITY IN ACID SOIL AND YIELD OF *Zea mays* L

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Chairman : Prof., Ahmed Osumanu Haruna, PhD
Faculty : Agriculture and Food Sciences (Bintulu)

The reaction of $H_2PO_4^{2-}$ and HPO_4^- with Al and Fe in acid soils to form a precipitate reduces diffusion of phosphorus into roots. The use of large amounts of lime and phosphorus fertilizers to saturate Al and Fe ions on acid soil so as to maintain sufficient supply of plant-available phosphorus is uneconomical. Biochar has been used to improve soil exchangeable phosphorus availability by decreasing soil acidity, Fe, and Al. However, there is limited information on the optimum rate of biochar and Triple Superphosphate (TSP) to increase phosphorus availability. The objectives of this study were to improve: (i) phosphorus availability in acid soils using TSP and chicken litter biochar and (ii) phosphorus uptake, agronomic efficiency, and yield of *Zea mays* L. Different rates of chicken litter biochar (25%, 50%, and 75%) of 5 t ha^{-1} and TSP (25%, 50%, and 75%) based on the recommended rate of 60 kg ha^{-1} phosphorus by MARDI were evaluated in incubation study (for 30, 60, and 90 days) and pot studies after which four promising treatments in the pot study were selected and evaluated in the field studies (first and second cycles). Selected soil physico-chemical properties, nutrient uptake, growth variable, and yield were determined using standard procedures. The incubation study results indicated that chicken litter biochar increased soil CEC and exchangeable K, Ca, Mg, and Na. Significant amounts of Al and Fe were fixed within the first 30 days of incubation suggesting that biochar can be used in tropical acid soils to reduced nutrients fixation by these ions. The results in the pot study showed that the maize plants in the soils amended with chicken litter biochar absorbed more of the phosphorus fertilizer and most of the absorbed phosphorus were translated into the crops dry matter production as compared with that of the normal fertilization. The use of 25% and 50% chicken litter biochar of 5 t ha^{-1} with 75% TSP increased maize plant dry matter more than that of the normal fertilization due increase in phosphorus availability thus, confirming the finding in the incubation study.

Further evaluation of treatments with 25% and 50% chicken litter biochar of 5 t ha^{-1} with 75% TSP in the field increased maize grain yield (8.44 t ha^{-1}) compared with normal fertilization (5.97 t ha^{-1}). Phosphate fertilizer reduced in the first and second field trials by 63.9%. Chicken litter biochar use was also reduced by 75% and 50% of 5 t ha^{-1}. These findings are also consistent with the findings in the incubation and pot study that, 25% and 50% biochar of 5 t ha^{-1} with 75% TSP is the optimum combination of chicken litter biochar and TSP to increase phosphorus availability, retention, phosphorus recovery and use efficiency, and maize grain yield.

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

KESAN *CHICKEN LITTER BIOCHAR* PADA KETERSEDIAAN FOSFORUS DI TANAH BERASID DAN HASIL *Zea mays* L

Oleh

AUDREY ANAK ASAP

November 2017

Pengerusi : Prof., Ahmed Osumanu Haruna, PhD
Fakulti : Sains Pertanian dan Makanan (Bintulu)

Reaksi $H_2PO_4^{2-}$ dan HPO_4^{-} dengan Al dan Fe dalam tanah asid membentuk endapan yang akan mengurangkan penyebaran fosforus ke akar. Penggunaan kapur dan baja fosforus yang banyak untuk menepukan ion Al dan Fe pada tanah asid bagi mengekalkan mengekalkan bekalan fosforus yang sedia ada adalah tidak ekonomik. Biochar telah digunakan untuk memperbaiki ketersediaan fosforus yang boleh ditukar tanah dengan mengurangkan keasidan tanah, Fe, dan Al. Walau bagaimanapun, terdapat maklumat yang terhad mengenai kadar optimum biochar dan *Triple Superphosphate* (TSP) untuk meningkatkan ketersediaan fosforus. Objektif kajian ini adalah untuk meningkatkan: (i) ketersediaan fosforus dalam tanah asid menggunakan TSP dan *chicken litter biochar* dan (ii) pengambilan fosforus, kecekapan agronomi dan hasil *Zea mays* L. Kadar yang berbeza dari *chicken litter biochar* (25% 50%, dan 75%) daripada 5 t ha^{-1} dan TSP (25%, 50%, dan 75%) berdasarkan kadar yang disyorkan sebanyak 60 kg ha^{-1} fosforus oleh MARDI dinilai dalam kajian inkubasi (30, dan 90 hari) dan kajian pasu yang mana empat rawatan terbaik dalam kajian pasu telah dipilih dan dinilai dalam kajian lapangan (kitaran pertama dan kedua). Ciri-ciri fiziko-kimia tanah yang dipilih, pengambilan nutrien, pemboleh ubah pertumbuhan, dan hasil ditentukan menggunakan prosedur piawai. Hasil kajian inkubasi menunjukkan bahawa *chicken litter biochar* meningkat CEC tanah dan *exchangeable* K, Ca, Mg, dan Na. Jumlah Al dan Fe yang ketara telah diikat dalam tempoh 30 hari pertama inkubasi yang menunjukkan bahawa biochar boleh digunakan di tanah asid tropika untuk mengurangkan kadar penetapan nutrien oleh ion-ion ini. Keputusan di dalam kajian pasu menunjukkan bahawa pokok jagung di tanah yang diubah dengan *chicken litter biochar* menyerap lebih banyak baja fosforus dan kebanyakan fosforus yang diserap telah diterjemahkan ke dalam hasil kering tanaman dibandingkan dengan pembajaan biasa. Penggunaan 25% dan 50% *chicken litter biochar* daripada 5 t ha^{-1} dengan 75% TSP meningkatkan bahan kering pokok jagung lebih daripada pembajaan biasa kerana kenaikan fosforus dengan itu, mengesahkan penemuan dalam kajian inkubasi.

Penilaian lanjut rawatan dengan 25% dan 50% *chicken litter biochar* 5 t ha^{-1} dengan 75% TSP dalam bidang meningkatkan hasil jagung jagung (8.44 t ha^{-1}) berbanding dengan pembajaan biasa (5.97 t ha^{-1}). Baja fosfat dikurangkan dalam ujian lapangan pertama dan kedua sebanyak 63.9%. Penggunaan *chicken litter biochar* juga dikurangkan sebanyak 75% dan 50% daripada 5 t ha^{-1}. Penemuan ini juga konsisten dengan penemuan dalam kajian inkubasi dan pasu, 25% dan 50% biochar dari 5 t ha^{-1} dengan 75% TSP adalah kombinasi optimum *chicken litter biochar* dan TSP untuk meningkatkan ketersediaan fosforus, pengekalan, pemulihan dan kecekapan penggunaan fosforus, dan hasil bijirin jagung.

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Ahmed Osumanu Haruna, PhD
Professor
Faculty of Agriculture and Food Science
Universiti Putra Malaysia
(Chairman)

Nik Muhamad B. Nik Abdul Majid, PhD
Professor
Institute of Tropical Forestry and Forest Product
Universiti Putra Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
University Putra Malaysia

Date:

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
AE_P	Agronomic Efficiency of the applied P
Al	Aluminium
ANOVA	Analysis of variance
Ca	Calcium
CEC	Cation exchange capacity
CRD	Completely Randomized Design
DAI	Days after incubation
DAS	Days after sowing
Fe	Iron
K	Potassium
KCl	Potassium chloride
MARDI	Malaysian Agriculture Research and Development Institute
Mg	Magnesium
MOP	Muriate of Potash
N	Nitrogen
Na	Sodium
OM	Organic matter
P	Phosphorus
RE_P	Crop recovery of the applied P
TC	Total carbon
TSP	Triple superphosphate
AEC	Anion exchange capacity
SE	Standard error

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

Orthophosphates are an essential macronutrients and component of the complex nucleic acid which when taken up as soluble inorganic P they regulate protein synthesis in plants structure (Mkhabela and Warman, 2005). Phosphate availability and use efficiency are very poor under acidic condition especially in Malaysian soil where most soils are high in Al and Fe due to high weathering and rainfall (Ch'ng *et al*., 2014a; Adnan *et al*., 2003). As an example, orthophosphates ($H_2PO_4^{2-}$ and HPO_4^-) react with Al and Fe to form a precipitate (Ch'ng *et al*., 2014a, b; Adnan *et al*., 2003). The reaction of $H_2PO_4^{2-}$ and HPO_4^- with Al and Fe ions to form a precipitate reduces diffusion of P into plant roots (Adnan *et al*., 2003) and conventionally, large amounts of lime and P fertilizers such as triple super phosphate (TSP) and rock phosphates are applied to acid soils to saturate Al and Fe ions (Rahman *et al*., 2014; Ch'ng *et al*., 2014a). This approach is to maintain sufficient supply of plant-available P (Rahman *et al*., 2014; Ch'ng *et al*., 2014a; Myers and De Pauw, 1995) however, approach is not only uneconomical but it is also not environmental friendly. The approach also wastes the limited P resources. Moreover, the Ca in lime could fix P in the soil thereby compounding the problem of P fixation. Hence, the need for more sustainable and environmentally friendly methods of improving tropical acid soils' P availability.

Apart from P fixation, excessive P application due to P limitation in soils especially those in the tropical acid soils diffuses into rivers and lakes causing algae bloom (Andersson *et al*., 2013) which causes eutrophication of freshwater (Vohla *et al*., 2011). Hence, there is a need to increase efficient utilization of P fertilizers in tropical acid soil in a more sustainable manner through the use of organic soil amendments.This is because, the availability of soil P can be improved in tropical acid soils with the addition of organic amendments (Ohno and Amirbahma, 2010; Ohno *et al*., 2007). For example, the use of organic amendments in the tropics will increase nutrient uptake (Uzoma *et al*., 2011; Lehmann and Rondon, 2006), apart from improving soil organic matter and soil pH to render P availability for optimum crop uptake (Smithson, 1999). There are many types of organic amendments but the use of biochar has recently gained popularity due to its numerous benefits.

Applying biochar to soils along with natural or synthetic fertilizers has been found to increase the bioavailability and plant uptake of phosphorus (P), alkaline metals and some trace metals (Steiner *et al*., 2007; Lehmann *et al*., 2003; Glaser *et al*., 2002). Biochar additions to soil have been reported to stimulate mycorrhizal infection (Ishii and Kadoya, 1994; Saito, 1990) and P solubility in soils (Gundale and DeLuca, 2007). The mediation of nutrient turnover by biochar has significant implications for organic agricultural systems where biochar may increase stabilization of organic nutrient sources (Glaser *et al*., 2001) and reduce nutrient leaching losses (Lehmann *et al*., 2003). These are because

biochar is a high surface area, highly porous, variable charge organic material that has the potential to increase soil water-holding capacity, cation exchange capacity (CEC), surface sorption capacity, and base saturation when added to soil (Liang *et al*., 2006; Keech *et al*., 2005; Bélanger *et al*., 2004; Glaser *et al*., 2002).The surface area, porosity, nutrient content, and charge density all change in relation to the temperature of biochar formation (Bornermann *et al*., 2007; Gundale and DeLuca, 2006). Biochar additions to soil also have the potential to alter soil microbial populations and to shift functional groups (Pietikäinen *et al*., 2000) besides having the potential to reduce soil bulk density (Gundale and DeLuca, 2006).

A recent study by Ch'ng *et al*. (2014a) showed that, when a tropical acid soil was amended with biochar, soil total P, available P, organic P, and inorganic fractions of P (soluble-P, Al-P, Fe-P, redundant soluble-P, and Ca-P) increased whereas soil exchangeable acidity, Fe, and Al reduced. Although Ch'ng *et al*. (2014a) used biochar to improve P availability of TSP, their study did not optimize the utilization of both biochar and TSP as these materials were not varied. Their study focused only on fixed amounts of TSP and biochar. Hence, there is a need to determine the optimum rates of biochar and TSP so as to render the use of these materials in agriculture economically. It is hypothesized that the use of the right amounts of chicken litter biochar and TSP will significantly increase soil available P, P use efficiency, and yield of crops in a sustainable manner.

1.2 Objectives

The objectives of this study were:

1. To improve phosphorus availability in acid soils by optimizing the use of TSP and chicken litter biochar.
2. To improve phosphorus uptake, agronomic efficiency, and yield of *Zea mays* L. on a tropical acid soil based on the best combination of chicken litter biochar and TSP.

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