UNIVERSITI PUTRA MALAYSIA

OPTIMIZING CHICKEN LITTER BIOCHAR AND EGYPT ROCK PHOSPHATE TO IMPROVE DRY MATTER PRODUCTION OF MAIZE REDUCING PHOSPHORUS FIXATION IN A TROPICAL ACID SOIL

SIMON ANAK MEDIN

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By

SIMON ANAK MEDIN

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

March 2019

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DEDICATION

Dedicate to my families and friends.
Thank you for everything.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

OPTIMIZING CHICKEN LITTER BIOCHAR AND EYGPT ROCK PHOSPHATE TO IMPROVE DRY MATTER BY REDUCING PHOSPHORUS FIXATION IN A TROPICAL ACID SOIL

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SIMON ANAK MEDIN

March 2019

Chairman : Professor Ahmed Osumanu Haruna, PhD
Faculty : Agriculture and Food Sciences (Bintulu Campus)

Soluble inorganic Phosphorus (P) in soils readily reacts with Aluminium and Iron because P predominate in soil solution, depending on soil pH, and remains immobile due to its fixation with hydrous and oxides. Biochar which bear functional groups with negative charges, have reported to improve acid soils with biochar or a mixture of biochar increased total P, available P, inorganic P fractions, to improve soil porosity and surface area. However, there is lack of information on the optimum use of biochar and P fertilizers to reduce P fixation especially for Egypt Rock Phosphate (ERP). The objectives of this study were to: (i) determine the optimum amount of P and biochar that could reduce phosphorus fixation and (ii) improve dry matter production of *Zea mays* L. by reduction of phosphorus fixation using biochar. Different rates of chicken litter biochar (75%, 50%, and 25%) and ERP (75%, 50%, and 25%) were evaluated in incubation study (for 30, 60, and 90 days) and pot studies. Soil samples were analysed on selected soil physico-chemical properties, nutrient uptake, and growth variable properties before and after leaching, incubation, and pot studies using standard procedures. Incubation study results showed that total P, pH, K, and Mg of leachates with 75% biochar were significantly higher due to the liming effect of the chicken litter biochar. The pH, total C and P, exchangeable P, water soluble P, after 30 days of leaching were significantly higher than that of the existing fertilization recommendation. The use of 75% biochar of 10 t ha^{-1} with 50% and 25% ERP showed significant retention and nutrients availability because of reduction of Al and Fe hydrolysis. Soil pH, total P, available P, and water soluble P increased in the treatments with 75% biochar for incubation study. Total acidity, exchangeable Al^{3+}, and H^{+} were significantly reduced by the chicken litter biochar. The use of 75% of 10 t ha^{-1} biochar with 25% ERP of the existing recommendation enhance phosphate release from ERP amended by minimizing soil Al and Fe hydrolysis. The results in the pot study suggest the use of 75% biochar of 10 t ha^{-1} with 25% ERP increased soil P availability, P uptake and dry matter yield of *Zea mays* L. Maize productivity can

be improved by using chicken litter biochar with 25% reduction of ERP. Generally, improving phosphorus use efficiency and yield of *Zea mays* L. cultivation on an acid soil using chicken litter biochar reduced chicken litter biochar and P fertilizer application rate, improved P availability, P uptake, and increase yield of *Zea mays* L. This study may only be applicable to tropical acid soils and it will as well contribute to the optimum utilization of P fertilizers and chicken litter biochar on tropical acid soil to improve *Zea mays* L. production. Further studies especially field trials are essential for consolidation of the research findings which reported in the thesis.

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

MENGOPTIMASI BIOCHAR TAHI AYAM DAN BAJA BATUAN FOSFORUS EYGPT UNTUK MENINGKATKAN HASIL KERING DENGAN MENGURANGKAN PENGIKATAN FOSFORUS DI TANAH ASID TROPIKA

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Fosforus (P) bukan organik dalam tanah mudah bereaksi dengan Al dan Fe kerana P bukan organik berlarut dan diikat oleh aluminium (Al) dan Ferum (Fe). Ini bergantung kepada kepada pH tanah, dan tetap tidak bergerak kerana diikat oleh hidrous dan oksida. Biochar yang mengandungi kumpulan berfungsi dengan cas negatif dilaporkan dapat meningkatkan tanah asid di mana biochar atau campuran biochar meningkat jumlah P, P tersedia, pecahan P organik dan untuk meningkatkan keliangan dan kawasan permukaan tanah. Walau bagaimanapun, terdapat maklumat yang terhad berkenaan penggunaan optimum biochar dan baja P untuk mengurangkan penetapan P terutama untuk baja Egypt Rock Phosphate (ERP). Objektif kajian ini adalah untuk: (i) menentukan jumlah optimum P dan biochar yang boleh mengurangkan penetapan fosforus dan (ii) meningkatkan pengeluaran bahan kering *Zea mays* L. melalui pengurangan penetapan fosforus menggunakan biochar. Kadar berbeza biochar tahi ayam (75%, 50%, dan 25%) dan ERP (75%, 50%, dan 25%) dinilai dalam kajian inkubasi (30, 60, dan 90 hari) dan kajian pasu. Sampel tanah dianalisis untuk sifat-sifat kimia-fizikal tanah yang dipilih, pengambilan nutrien, dan sifat-sifat pemboleh ubah pertumbuhan sebelum dan selepas kajian larut lesap, kajian inkubasi, dan kajian pasu menggunakan prosedur piawai. Hasil kajian inkubasi menunjukkan bahawa jumlah keseluruhan P, pH, K, dan Mg yang larut dengan biochar 75% lebih tinggi disebabkan oleh kesan pengapuran biochar tahi ayam. Nilai pH, jumlah C dan P, kebolehtukaran P, kebolehlarutan P, selepas 30 hari larut lesap lebih tinggi daripada pembajaan biasa. Penggunaan biochar 75% daripada 10 t ha^{-1} dengan 50% dan 25% ERP menunjukkan ketersediaan ketahanan dan nutrien yang signifikan kerana pengurangan hidrolisis Al dan Fe. Nilai pH tanah, jumlah P, ketersediaan P, dan kebolehlarutan P meningkat dalam bahan pindaan dengan biochar 75% dalam kajian inkubasi. Keasidan tanah, kebolehtukaran Al^{3+}, dan H^{+} dikurangkan dengan ketara oleh biochar tahi ayam. Penggunaan 75% daripada 10 t ha^{-1} biochar dengan 25% ERP

dengan cadangan yang sedia ada merangsang pelepasan P dari ERP yang dipinda dengan meminimumkan hidrolisis Al dan Fe dalam tanah. Keputusan kajian pasu menunjukkan penggunaan biochar 75% daripada 10 t ha^{-1} dengan 25% ERP meningkat ketersediaan P tanah, pengambilan P dan hasil bahan kering *Zea mays* L. Produktiviti jagung dapat ditingkatkan dengan menggunakan biochar tahi ayam dengan 25 % pengurangan penggunaan baja ERP. Secara amnya, peningkatan fosforus menggunakan kecekapan dan hasil penanaman *Zea mays* L. pada tanah asid menggunakan biochar tahi ayam telah mengurangkan biochar tahi ayam dan kadar penggunaan baja P, peningkatan ketersediaan P, peningkatan pengambilan P dan peningkatan hasil *Zea mays* L. Kajian ini boleh digunakan untuk tanah asid tropika dan ia juga akan menyumbang kepada pemanfaatan optimum baja P dan biochar tahi ayam pada tanah asid tropika untuk meningkatkan pengeluaran *Zea mays* L.

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

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LIST OF ABBREVIATIONS

$(NH_4)_2Fe(SO_4)_2.6H_2O$	Ferrous Ammonium Sulphate
ADP	Adenosine Diphosphate
Anion Exchange Capacity	Methane
Al-P_i	Aluminium Bound Inorganic Phosphorus
ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
Ca-P_i	Calcium Bound Inorganic Phosphorus
COD	Chemical Oxygen Demand
DAI	Days After Incubation
DAS	Days After Sowing
Fe-P_i	Iron Bound Inorganic Phosphorus
P	Phosphorus
P_i	Inorganic Phosphorus
P_o	Organic Phosphorus
SAS	Statistical Analysis System
SE	Standard Error

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

Phosphorus (P) is an essential macronutrient for plant growth. The optimum phosphorus available for uptake in crops occurs at soil pH range from 6 to 7. Although when P is supplied as soluble fertilizer, availability of P is low in a solution of most soils due to P fixation by positively charged minerals in soils (Ayaga *et al*., 2006). Phosphorus plays a vital role in plant nutrition (Stribley *et al*., 1980) but readily available P is limited in agriculture (Vassilev *et al*., 2006). Moreover, a soluble source of P following application of chemical and organic fertilizers to soils are fixed by Al and Fe ions to form highly insoluble compounds (Brady and Weil, 2008). Phosphorus fixation is the reduction of solubility in P uptake by crops. The soils in the tropics are mostly acidic, which due to excessive weathering and high precipitation, resulting in basic cations loses (Ch'ng *et al*., 2016). Soluble inorganic P in soils can readily react with Al and Fe because P predominate in soil solution, depending on soil pH, and remains immobile due to the fixation with hydrous and oxides of Fe and Al ions (Ch'ng *et al*., 2016; Ch'ng *et al*., 2015; Adnan *et al*., 2003). As an example, orthophosphates ($H_2PO_4^{2-}$ and HPO_4^{2-}) react with Al^{3+} and Fe^{2+} to form precipitate and this reaction reduces diffusion of P into roots (Adnan *et al*., 2003).

Liming, as well as standard usage of P fertilizers, are the typical practices that had been utilized to alleviate P fixation in acid soils. To retain a sufficient plant-available P supply, liming is applied to decrease the solubility of Al and Fe ions. Likewise, unnecessary use of P fertilizers causes eutrophication (Brady and Weil, 2008). Some studies have shown that application of regular inorganic fertilizer, for example, phosphate and triple superphosphate, is not economical as well as environmentally friendly (Asap *et al*., 2018; Rahman *et al*., 2014). It is well-known that the uncontrolled application of P fertilizers can lead to water pollution, eutrophication (Ch'ng *et al*., 2016).

The mitigation of P fixation in tropical acid soils involved the application of organic amendments which can decrease P sorption sites (Ch'ng *et al*., 2016; Ohno and Amirbahma, 2010; Ohno *et al*., 2007). Biochar is alkaline in nature thus, it could increase soil pH (Ch'ng *et al*., 2016) for optimum crop productivity. Biochar, a carbon material created as a soil improver for agricultural and environmental management (Ch'ng *et al*., 2014; Alvum-Toll *et al*., 2011). Addition of biochar improves soil surface area and porosity. Besides, these materials tolerate negatively charged groups that can absorb Al and Fe ions, thus decreasing the P fixation in soil (Qayyum *et al*., 2015). According to Ch'ng *et al.* (2014), improving acid soils with biochar as well as mixtures of biochar able to increase total P, available P, inorganic P fractions, and organic P. This was because organic amendments have the tendency not only increasing soil pH, but also decreasing acidity by reducing exchangeable Al ion as well as exchangeable Fe ion (Ch'ng *et al*., 2014).

Application of combination biochar and Christmas Island Rock Phosphate (CIRP) successfully fixed Al and Fe ions. Therefore, available P will be more available for plants in extended period in comparison to applying CIRP without organic amendments (Ch'ng *et al*., 2016a). Organic amendments increased N, K, Ca and Mg availability in soils, and they as well enhanced nutrients uptake and production of dry matter of Zea mays (Ch'ng *et al*., 2016b). Usage of biochar, as well as compost, can minimize usage of phosphate fertilizers and lime (Ch'ng *et al*., 2016c). Biochar application can possibly tackle climate change through carbon sequestration (Liu *et al*., 2014; Lehmann, 2007), soil physicochemical and biological properties (Xu *et al*., 2014; Sohi *et al*., 2010; Glaser *et al*., 2002). Previous studies had been done for P using organic matter for sorption and fixation (Ohno and Amirbahma, 2010; Ohno *et al*., 2007). However, information on the optimum usage of biochar and P fertilizer to reduce P fixation is lacking (Ch'ng *et al*., 2014). This is especially for Egypt Rock Phosphate (ERP) which currently one of the popular P fertilizers being used in agriculture (Ch'ng *et al.,* 2016c). It was hypothesized that lower than recommended biochar rates and Egypt Rock Phosphate (ERP) on tropical acid soil will have a similar effect on improving P availability on crop productivity, compare to recommended rates. This study will try to explore the optimum amount of biochar that could reduce phosphorus fixation and improve crop yield be determined.

1.2 Objectives

Objectives of this study were to:

1. Determine optimum amount of biochar reduce phosphorus fixation.
2. Improve dry matter production of *Zea mays* L. by reduction phosphorus fixation using biochar.

REFERENCES

Adnan, A., Mavinic, D. S., and Koch, F. A. (2003). Pilot-scale study of phosphorus recovery through struvite crystallization examining the process feasibility. *Journal of environmental engineering and science*, *2*(5), 315-324. DOI: 10.1139/s03-040.

Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D. & Ok, Y. S. (2014). Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere*, *99*, 19-33.

Alvum-Toll, K., Karlsson, T., & Ström, H. (2011). Biochar as soil amendment.

Asap, A., Haruna, A. O., Majid, N. M. A., & Ali, M. (2018). Amending triple superphosphate with chicken litter biochar improves phosphorus availability. *Eurasian Journal of Soil Science*, *7*(2), 121-132. DOI : 10.18393/ejss.376250

Askegaard, M., Olesen, J. E., Rasmussen, I. A., and Kristensen, K. (2011). Nitrate leaching from organic arable crop rotations is mostly determined by autumn field management. *Agriculture, ecosystems & environment*, *142*(3), 149-160. DOI: 10.1016/j.agee.2011.04.014.

Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and soil*, *337*(1-2), 1-18.

Atkinson, C. J., Fitzgerald, J. D., and Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and soil*, *337*(1-2), 1-18. DOI: 10.1007/s11104-010-0464-5.

Ayaga, G., Todd, A., & Brookes, P. C. (2006). Enhanced biological cycling of phosphorus increases its availability to crops in low-input sub-Saharan farming systems. *Soil Biology and Biochemistry*, *38*(1), 81-90.

Bates, T. R., & Lynch, J. P. (2001). Root hairs confer a competitive advantage under low phosphorus availability. *Plant and Soil*, *236*(2), 243-250.

Beck, M. A., & Sanchez, P. A. (1994). Soil phosphorus fraction dynamics during 18 years of cultivation on a Typic Paleudult. *Soil Science Society of America Journal*, *58*(5), 1424-1431.

Beegle, D. B., & Durst, P. T. (2002). Managing phosphorus for crop production. *Agronomy Facts*, *13*, 6.

Beesley, L., Moreno-Jiménez, E., Gomez-Eyles, J. L., Harris, E., Robinson, B., & Sizmur, T. (2011). A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. *Environmental pollution*, *159*(12), 3269-3282.

Bennett, E. M., Carpenter, S. R., & Caraco, N. F. (2001). Human impact on erodable phosphorus and eutrophication: a global perspective: increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication. *AIBS Bulletin*, *51*(3), 227-234.

Beqiraj, E., Gjoka, F., Muller, F., & Bailif, P. (2008). Use of zeolitic material from Munella region (Albania) as fertilizer in the sandy soils of Divjaka region (Albania). *Carpathian Journal of Earth and Environmental Sciences*, *2*, 33-47.

Berek, A. K., Radjagukguk, B., & Maas, A. (1995). The effect of different organic materials on the alleviation of Al toxicity in soybean on a red-yellow podzolic soil. In *Plant-soil interactions at low pH: Principles and management* (pp. 579-584). Springer, Dordrecht.

Bernas, B. (1968). New method for decomposition and comprehensive analysis of silicates by atomic absorption spectrometry. *Analytical Chemistry*, *40*(11): 1682-1686. DOI: 10.1021/ac60267a017.

Bernas, B. (1968). New method for decomposition and comprehensive analysis of silicates by atomic absorption spectrometry. *Analytical Chemistry*, *40*(11): 1682-1686. DOI: 10.1021/ac60267a017.

Bianchi, S. R., Miyazawa, M., Oliveira, E. L. D., & Pavan, M. A. (2008). Relationship between the mass of organic matter and carbon in soil. *Brazilian Archives of Biology and Technology*, *51*(2), 263-269.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. *Agronomy journal*, *54*(5): 464-465.

Brady, N. C., and Weil, R. R. (1999). The nature and properties of soil 12th ed.

Bremner, J.M. (1965). Total Nitrogen. In *Method of soil analysis part 2*, ed. C.A. Black, D.D. Evan, L.E. Ensminger, J.L. White, F.E. Clark, and R.D. Dinauer, pp. 1149-1178. *American Society of Agronomy*. Madison, Wisconcin.

Bricker, S. B., Clement, C. G., Pirhalla, D. E., Orlando, S. P., & Farrow, D. R. (1999). *National estuarine eutrophication assessment: effects of nutrient enrichment in the nation's estuaries*. US National Oceanographic and Atmospheric Administration, National Ocean Service, Special Projects Office and the National Center for Coastal Ocean Science.

Brookes, P. C., Powlson, D. S., & Jenkinson, D. S. (1984). Phosphorus in the soil microbial biomass. *Soil biology and biochemistry*, *16*(2), 169-175.

Cakmak, I., & Marschner, H. (1986). Mechanism of phosphorus- induced zinc deficiency in cotton. I. Zinc deficiency- enhanced uptake rate of phosphorus. *Physiologia Plantarum*, *68*(3), 483-490.

Campbell, K. L., & Edwards, D. R. (2001). Phosphorus and water quality impacts. *Agricultural Nonpoint Source Pollution: Watershed Management and Hydrology*, 91-108.

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological applications*, *8*(3), 559-568.

Case, S. D., McNamara, N. P., Reay, D. S., and Whitaker, J. (2012). The effect of biochar addition on N_2O and CO_2 emissions from a sandy loam soil–the role of soil aeration. *Soil Biology and Biochemistry*, *51*, 125-134. DOI: 10.1016/j.soilbio.2012.03.017.

Cely, P., Gascó, G., Paz-Ferreiro, J., & Méndez, A. (2015). Agronomic properties of biochars from different manure wastes. *Journal of Analytical and Applied Pyrolysis*, *111*, 173-182.

Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A., & Joseph, S. (2008). Agronomic values of greenwaste biochar as a soil amendment. *Soil Research*, *45*(8), 629-634.

Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A., & Joseph, S. (2008). Using poultry litter biochars as soil amendments. *Soil Research, 46*(5), 437-444.

Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A., & Joseph, S. (2008). Agronomic values of greenwaste biochar as a soil amendment. *Soil Research*, *45*(8), 629-634.

Chan, K. Y., Van Zwieten, L., Meszaros, I., Downie, A., and Joseph, S. (2007). Agronomic values of greenwaste biochar as a soil amendment. *Soil Research*, *45*(8), 629-634. DOI: 10.1071/SR07109.

Chefetz, B., Hatcher, P. G., Hadar, Y., and Chen, Y. (1996). Chemical and biological characterization of organic matter during composting of municipal solid waste. *Journal of Environmental Quality*, *25*(4), 776-785. DOI: 10.2134/jeq1996.00472425002500040018x.

Chen, J., Liu, X., Zheng, J., Zhang, B., Lu, H., Chi, Z Pan, G., Li, L., Zheng, J., Zhang, X. and Wang, J. (2013). Biochar soil amendment increased bacterial but decreased fungal gene abundance with shifts in community structure in a slightly acid rice paddy from Southwest China. Applied Soil Ecology, 71, 33-44. https://doi.org/10.1016/j.apsoil.2013.05.003

Cheng, C. H., Lehmann, J., and Engelhard, M. H. (2008). Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. *Geochimica et Cosmochimica Acta*, *72*(6), 1598-1610. DOI: 10.1016/j.gca.2008.01.010.

Ch'ng, H. Y., Ahmed, O. H., and Majid, N. M. A. (2014). Biochar and compost influence the phosphorus availability, nutrients uptake, and growth of maize (*Zea mays* L.) in tropical acid soil. *Pakistan Journal of Agricultural Sciences, 51*(4), 797-806.

Ch'ng, H. Y., Ahmed, O. H., and Majid, N. M. A. (2016a). Improving phosphorus availability, nutrient uptake and dry matter production of *Zea mays* L. on a tropical acid soil using poultry manure biochar and pineapple leaves compost. *Experimental Agriculture, 52*(3), 447-465. DOI: 10.1017/S0014479715000204.

Ch'ng, H. Y., Ahmed, O. H., and Majid, N. M. A. (2016b). Minimizing Phosphorus Sorption and Leaching in a Tropical Acid Soil Using Egypt Rock Phosphate with Organic Amendments. *Philippine Agricultural Scientist, 99*(2), 176-185.

Ch'ng, H. Y., Ahmed, O. H., Majid, N. M. A., and Jalloh, M. B. (2016c). Reducing Soil Phosphorus Fixation to Improve Yield of Maize on a Tropical Acid Soil Using Compost and Biochar Derived from Agro-Industrial Wastes. *Compost Science & Utilization*, 1-13. DOI: 10.1080/1065657X.2016.1202795.

Christianson, L., Bhandari, A., and Helmers, M. (2009). Emerging technology: Denitrification bioreactors for nitrate reduction in agricultural waters. *Journal of soil and water conservation, 64*(5), 139A-141A. DOI: 10.2489/jswc.64.5.139A.

Coelho, B. B., Murray, R., Lapen, D., Topp, E., and Bruin, A. (2012). Phosphorus and sediment loading to surface waters from liquid swine manure application under different drainage and tillage practices. *Agricultural Water Management, 104*, 51-61. DOI: 10.1016/j.agwat.2011.10.020.

Cooper, J., Lombardi, R., Boardman, D., & Carliell-Marquet, C. (2011). The future distribution and production of global phosphate rock reserves. *Resources, Conservation and Recycling, 57*, 78-86.

Cordell, D., Drangert, J. O., & White, S. (2009). The story of phosphorus: global food security and food for thought. *Global environmental change, 19*(2), 292-305.

Cottenie, A. 1980. Soil testing and plant testing as a basis of fertilizer recommendation. FAO Soils Bulletin 38: 70-73.

De Ridder, M., De Jong, S., Polchar, J., & Lingemann, S. (2012). *Risks and opportunities in the global phosphate rock market: Robust strategies in times of uncertainty*. Hague Centre for Strategic Studies.

Del-Pilar-Ruso, Y., De-la-Ossa-Carretero, J. A., Loya-Fernández, A., Ferrero-Vicente, L. M., Giménez-Casalduero, F., & Sánchez-Lizaso, J. L. (2009). Assessment of soft-bottom Polychaeta assemblage affected by a spatial confluence of impacts: sewage and brine discharges. *Marine Pollution Bulletin, 58*(5), 776.

DeLuca, T. H., Gundale, M. J., MacKenzie, M. D., & Jones, D. L. (2015). Biochar effects on soil nutrient transformations. *Biochar for environmental management: science, technology and implementation*, *2*, 421-454.

Déry, P., & Anderson, B. (2007). Peak phosphorus. *Energy Bulletin*, *13*.

Dixon, R. K., and Wisniewski, J. (1995). Global forest systems: An uncertain response to atmospheric pollutants and global climate change?. *Water, Air, and Soil Pollution*, *85*(1), 101-110.

Dobermann, A.R. 2005. Nitrogen Use Efficiency – *State of the Art*. *Agronomy - Faculty Publications*. Paper 316. http://digitalcommons.unl.edu/agronomyfacpub/316.

Drolc, A., & Koncan, J. Z. (2002). Estimation of sources of total phosphorus in a river basin and assessment of alternatives for river pollution reduction. *Environment International*, *28*(5), 393-400.

Drury, C. F., Tan, C. S., Gaynor, J. D., Reynolds, J. W. D., Welacky, T. W., and Oloya, T. O. (2001). Water table management reduces tile nitrate loss in continuous corn and in a soybean-corn rotation. *The Scientific World Journal*, *1*, 163-169. DOI: 10.1100/tsw.2001.268.

Duku, M. H., Gu, S., & Hagan, E. B. (2011). Biochar production potential in Ghana—a review. *Renewable and Sustainable Energy Reviews*, *15*(8), 3539-3551.

Fageria, N. K., & Baligar, V. C. (2008). Ameliorating soil acidity of tropical Oxisols by liming for sustainable crop production. *Advances in agronomy*, *99*, 345-399.

Fang, X., Chua, T., Schmidt-Rohr, K., and Thompson, M. L. (2010). Quantitative 13 C NMR of whole and fractionated Iowa Mollisols for assessment of organic matter composition. *Geochimica et Cosmochimica Acta*, *74*(2), 584-598. DOI: 10.1016/j.gca.2009.10.008.

FAO, (1995). Global and National Soils and Terrain Digital Database (SOTER) - Procedures Manual. FAO World Soil Resources Reports. No.74, Rev.1. Rome.

Fest, E. P., Temminghoff, E. J. M., Comans, R. N. J., & Van Riemsdijk, W. H. (2008). Partitioning of organic matter and heavy metals in a sandy soil: effects of extracting solution, solid to liquid ratio and pH. Geoderma, 146(1-2), 66-74.

Gachene, C. K., and Kimaru, G. (Eds.). (2003). *Soil fertility and Land productivity: A guide for extension workers in the Eastern Africa Region* (No. 30). Regional Land Management Unit.

Gaskin, J. W., Steiner, C., Harris, K., Das, K. C., and Bibens, B. (2008). Effect of low-temperature pyrolysis conditions on biochar for agricultural use. *Transactions of the ASABE*, *51*(6), 2061-2069. DOI: 10.13031/2013.25409.

GEOSEA V Proceedings Vols.1 & II, Fifth Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia, Kuala Lumpur, 9-13 April 1984. Edited by G.H. Teh & S. Paramananthan.

Gitari, H. I., Mochoge, B. E., & Danga, B. O. (2015). Effect of lime and goat manure on soil acidity and maize (Zea mays) growth parameters at Kavutiri, Embu County-Central Kenya. *Journal of Soil Science and Environmental Management*, *6*(10), 275-283.

Githae, E. W., Gachene, C. K., & Njoka, J. T. (2011). Soil physicochemical properties under Acacia senegal varieties in the dryland areas of Kenya. African Journal of Plant Science, 5(8), 475-482.

Glaser, B., Haumaier, L., Guggenberger, G., and Zech, W. (2001). The'Terra Preta'phenomenon: a model for sustainable agriculture in the humid tropics. *Naturwissenschaften*, *88*(1), 37-41. DOI: 10.1007/s001140000193.

Glaser, B., Lehmann, J., & Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal–a review. *Biology and fertility of soils*, *35*(4), 219-230.

Glaser, B., Lehmann, J., and Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-a review. *Biology and fertility of soils*, *35*(4), 219-230. DOI: 10.1007/s00374-002-0466-4.

Guppy, C. N., Menzies, N. W., Moody, P. W., & Blamey, F. P. C. (2005). Competitive sorption reactions between phosphorus and organic matter in soil: a review. *Soil Research*, *43*(2), 189-202.

Hashimoto, Y., Matsufuru, H., Takaoka, M., Tanida, H., & Sato, T. (2009). Impacts of chemical amendment and plant growth on lead speciation and enzyme activities in a shooting range soil: an X-ray absorption fine structure investigation. *Journal of environmental quality*, *38*(4), 1420-1428.

Haynes, R. J., & Mokolobate, M. S. (2001). Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. *Nutrient cycling in agroecosystems*, *59*(1), 47-63.

Heckenmüller, M., Narita, D., & Klepper, G. (2014). *Global availability of phosphorus and its implications for global food supply: an economic overview* (No. 1897). Kiel working paper.

Herath, H. M. S. K., Camps-Arbestain, M., & Hedley, M. (2013). Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol. *Geoderma*, *209*, 188-197.

Higgs, B., Johnston, A. E., Salter, J. L., & Dawson, C. J. (2000). Some aspects of achieving sustainable phosphorus use in agriculture. *Journal of Environmental Quality*, *29*(1), 80-87.

Hiradate, S., Furubayashi, A., Uchida, N., & Fujii, Y. (2007). Adsorption of 2, 4-dichlorophenoxyacetic acid by an Andosol. *Journal of environmental quality*, *36*(1), 101-109.

Holford, I. C. R. (1997). Soil phosphorus: its measurement, and its uptake by plants. *Soil Research*, *35*(2), 227-240.

Hopkins, B. G., Ellsworth, J. W., Shiffler, A. K., Bowen, T. R., & Cook, A. G. (2010). Pre-plant versus in-season application of phosphorus fertilizer for Russet Burbank potato grown in calcareous soil. *Journal of plant nutrition*, *33*(7), 1026-1039.

Howarth, R. W., & Marino, R. (2006). Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades. *Limnology and Oceanography*, *51*(1part2), 364-376.

Hue, N. V. (1992). Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. *Communications in soil science and plant analysis*, *23*(3-4), 241-264.

Hunt, J. F., & Ohno, T. (2007). Characterization of fresh and decomposed dissolved organic matter using excitation− emission matrix fluorescence spectroscopy and multiway analysis. *Journal of Agricultural and Food Chemistry*, *55*(6), 2121-2128.

Ismail, H., Shamshuddin, J., & Omar, S. S. (1993). Alleviation of soil acidity in Ultisol and Oxisol for corn growth. *Plant and Soil*, *151*(1), 55-65.

Iyamuremye, F., Dick, R. P., & Baham, J. (1996). Organic amendments and phosphorus dynamics: I. Phosphorus chemistry and sorption. *Soil Science*, *161*(7), 426-435.

Jaliya, M. M., Falaki, A. M., Mahmud, M., & Sani, Y. A. (2008). Effect of sowing date and NPK fertilizer rate on yield and yield components of quality protein maize (Zea mays L.). *ARPN Journal of Agricultural and Biological Science*, *3*(2), 23-29.

Jeffery, S., Abalos, D., Prodana, M., Bastos, A. C., Van Groenigen, J. W., Hungate, B. A., & Verheijen, F. (2017). Biochar boosts tropical but not temperate crop yields. *Environmental Research Letters*, *12*(5), 053001.

Jiao, Y., Whalen, J. K., and Hendershot, W. H. (2007). Phosphate sorption and release in a sandy-loam soil as influenced by fertilizer sources. *Soil Science Society of America Journal*, *71*(1), 118-124. DOI: 10.2136/sssaj2006.0028.

Jien, S. H., & Wang, C. S. (2013). Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena*, *110*, 225-233.

Jin, D. F., Xu, Y. Y., Zhang, M., Jung, Y. S., & Ok, Y. S. (2016). Comparative evaluation for the sorption capacity of four carbonaceous sorbents to phenol. *Chemical Speciation & Bioavailability*, *28*(1-4), 18-25.

Joseph, S., Peacocke, C., Lehmann, J., & Munroe, P. (2009). Developing a biochar classification and test methods. *Biochar for environmental management: Science and technology*, *1*, 107-126.

Kambo, H. S., & Dutta, A. (2015). A comparative review of biochar and hydrochar in terms of production, physico-chemical properties and applications. Renewable and Sustainable Energy Reviews, 45, 359-378.

Karhu, K., Mattila, T., Bergström, I., and Regina, K. (2011). Biochar addition to agricultural soil increased CH_4 uptake and water holding capacity–results from a short-term pilot field study. *Agriculture, Ecosystems and Environment*, *140*(1), 309-313. DOI: 10.1016/j.agee.2010.12.005.

Knight, J. N. (2013). *Quantifying Phosphorus Sources, Sinks, Flows and Footprints: Incorporating Phosphate Rock, Mineral Impurities and Natural Inputs* (Doctoral dissertation, University of Colorado Denver).

Knowles, O. A., Robinson, B. H., Contangelo, A., and Clucas, L. (2011). Biochar for the mitigation of nitrate leaching from soil amended with biosolids. *Science of the Total Environment*, *409*(17), 3206-3210. DOI: 10.1016/j.scitotenv.2011.05.011.

Laird, D. A. (2008). The charcoal vision: a win–win–win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. *Agronomy journal*, *100*(1), 178-181. DOI: 10.2134/agrojnl2007.0161.

Laird, D., Fleming, P., Wang, B., Horton, R., and Karlen, D. (2010a). Biochar impact on nutrient leaching from a Midwestern agricultural soil. *Geoderma*, *158*(3), 436-442. DOI: 10.1016/j.geoderma.2010.05.012.

Latifah, O., Ahmed, O. H., and Majid, N. M. A. (2017). Short Term Enhancement of Nutrients Availability in *Zea mays* L. Cultivation on an Acid Soil Using Compost and Clinoptilolite Zeolite. *Compost Science and Utilization*, *25*(1), 22-35. DOI: 10.1080/1065657X.2016.1172054.

Lehmann, J. (2007). A handful of carbon. Nature 447, 143-144.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., and Crowley, D. (2011). Biochar effects on soil biota–a review. *Soil biology and biochemistry*, *43*(9), 1812-1836. DOI: 10.1016/j.soilbio.2011.04.022.

Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'neill, B., Skjemstad, J.O., Thies, J., Luizao, F.J., Petersen, J. and Neves, E.G. (2006). Black carbon increases cation exchange capacity in soils. *Soil Science Society of America Journal*, *70*(5), 1719-1730.

Litke, D. W. (1999). *Review of phosphorus control measures in the United States and their effects on water quality*. Reston, VA: US Department of the Interior, US Geological Survey.

Lu, S. G., Sun, F. F., & Zong, Y. T. (2014). Effect of rice husk biochar and coal fly ash on some physical properties of expansive clayey soil (Vertisol). *Catena*, *114*, 37-44.

Maguire, R. O., & Sims, J. T. (2002). Soil testing to predict phosphorus leaching. *Journal of Environmental Quality*, *31*(5), 1601-1609.

Malaysian Agricultural Research and Development Institute (MARDI). 1993. Jagung manis baru (new sweet corn): masmadu. MARDI, Kuala Lumpur, Malaysia.

Mao, J. D., Johnson, R. L., Lehmann, J., Olk, D. C., Neves, E. G., Thompson, M. L., and Schmidt-Rohr, K. (2012). Abundant and stable char residues in soils: implications for soil fertility and carbon sequestration. *Environmental science and technology*, *46*(17), 9571-9576. DOI: 10.1021/es301107c.

Mehlich, A. (1953). Determination of P, Ca, Mg, K, Na and NH_4. North Carolina State University Soil Test Division, Raleigh, NC.

Mehlich, A. (1953). Determination of P, Ca, Mg, K, Na and NH_4. North Carolina State University Soil Test Division, Raleigh, NC.

Mensah, A. K., & Frimpong, K. A. (2018). Biochar and/or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. *International Journal of Agronomy*, *2018*.

Meyer-Reil, L. A., & Köster, M. (2000). Eutrophication of marine waters: effects on benthic microbial communities. *Marine Pollution Bulletin*, *41*(1-6), 255-263.

Mikan, C. J., and Abrams, M. D. (1996). Mechanisms inhibiting the forest development of historic charcoal hearths in south-eastern Pennsylvania. *Canadian journal of forest research*, *26*(11), 1893-1898. DOI: 10.1139/x26-213.

Mishra, P. K., Joshi, P., Suyal, P. R. E. E. T. I., Bisht, J. K., & Bhatt, J. C. (2014). Potential of phosphate solubilising microorganisms in crop production. *Bioresources for Sustainable Plant Nutrient Management. Satish Serial Publishing House, New Delhi-110033, India*, 201-222.

Mkhabela, M. S., & Warman, P. R. (2005). The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwash sandy loam soil in Nova Scotia. *Agriculture, ecosystems & environment*, *106*(1), 57-67.

Muhumed, M. A., Jusop, S., Sung, C. T. B., Wahab, P. E. M., & Panhwar, Q. A. (2014). Influence of NPK fertilizer rates and irrigation frequencies on the biomass and yield components of sweet corn (*Zea mays* L.). *Journal of Food, Agriculture & Environment*, *12*(2), 1308-1313.

Murphy, J. and Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica chimica acta*, *27*, 31-36. DOI: 10.1016/S0003-2670(00)88444-5.

Murphy, J. and Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica chimica acta*, *27*, 31-36. DOI: 10.1016/S0003-2670(00)88444-5.

Myers, R. G., Sharpley, A. N., Thien, S. J., & Pierzynski, G. M. (2005). Ion-sink phosphorus extraction methods applied on 24 soils from the continental USA. *Soil Science Society of America Journal*, *69*(2), 511-521.

Myers, R. J. K., and De Pauw, E. (1995). Strategies for the management of soil acidity. In *Plant-Soil Interactions at Low pH: Principles and Management* (pp. 729-741). Springer Netherlands.

Narambuye, F. X. and Haynes, R. J. (2006). Effect of organic amendments on soil pH and Al solubility and use of laboratory indices to predict their liming effect. Soil Science 17110(10):754–763

Nekesa A. O, Okaebo J.R., Otheno C.O., Thuita M. N., Kipsat M., Batiano A., Sanginga N., Kimettu J., and Vanlauwe B., (2005). The potential of Minjingu phosphate rock from Tanzania as a liming material: Effect on maize and bean intercrop on acid soils of western Kenya. *African Crop Science Conference Proceedings,* Vol. 7. pp. 1121-1128.

Nguyen, B. T., and Lehmann, J. (2009). Black carbon decomposition under varying water regimes. *Organic Geochemistry*, *40*(8), 846-853

Nguyen, B. T., Lehmann, J., Kinyangi, J., Smernik, R., Riha, S. J., and Engelhard, M. H. (2009). Long-term black carbon dynamics in cultivated soil. *Biogeochemistry*, *92*(1-2), 163-176.

Nigussie, A., Kissi, E., Misganaw, M., & Ambaw, G. (2012). Effect of biochar application on soil properties and nutrient uptake of lettuces (Lactuca sativa) grown in chromium polluted soils. *American-Eurasian Journal of Agriculture and Environmental Science*, *12*(3), 369-376.

Niu, Y. F., Chai, R. S., Jin, G. L., Wang, H., Tang, C. X., & Zhang, Y. S. (2012). Responses of root architecture development to low phosphorus availability: a review. *Annals of botany*, *112*(2), 391-408.

Nixon, S. W. (1995). Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia*, *41*(1), 199-219.

Novak, J. M., Busscher, W. J., Laird, D. L., Ahmedna, M., Watts, D. W., and Niandou, M. A. (2009a). Impact of biochar amendment on fertility of a south-eastern coastal plain soil. *Soil science*, *174*(2), 105-112.

Novak, J. M., Busscher, W. J., Laird, D. L., Ahmedna, M., Watts, D. W., and Niandou, M. A. (2009a). Impact of biochar amendment on fertility of a south-eastern coastal plain soil. *Soil science*, *174*(2), 105-112.

O'Connor, G. A., & Chinault, S. L. (2006). Environmental impacts of land applying biosolids. *Florida Water Resources Journal*.

Oad, F. C., Buriro, U. A., & Agha, S. K. (2004). Effect of organic and inorganic fertilizer application on maize fodder production. *Asian J. Plant Sci*, *3*(3), 375-377.

Ohno, T., and Amirbahman, A. (2010a). Phosphorus availability in boreal forest soils: a geochemical and nutrient uptake modeling approach. *Geoderma*, *155*(1), 46-54. DOI: 10.1016/j.geoderma.2009.11.022.

Ohno, T., Fernandez, I. J., Hiradate, S., and Sherman, J. F. (2007). Effects of soil acidification and forest type on water soluble soil organic matter properties. *Geoderma*, *140*(1), 176-187. DOI: 10.1016/j.geoderma.2007.04.004.

Ohno, T., He, Z., Sleighter, R. L., Honeycutt, C. W., & Hatcher, P. G. (2010b). Ultrahigh resolution mass spectrometry and indicator species analysis to identify marker components of soil-and plant biomass-derived organic matter fractions. *Environmental science & technology*, *44*(22), 8594-8600.

Osman, K.T. 2012. A nutrient is a chemical element needed for normal growth and reproduction of plants. *Soils: Principles, Properties, and Management*.

Páez-Osuna, F., & Ruiz-Fernández, A. C. (2005). Environmental load of nitrogen and phosphorus from extensive, semiintensive, and intensive shrimp farms in the Gulf of California ecoregion. *Bulletin of Environmental Contamination and Toxicology*, *74*(4), 681-688.

Páez-Osuna, F., Guerrero-Galván, S. R., & Ruiz-Fernández, A. C. (1998). The environmental impact of shrimp aquaculture and the coastal pollution in Mexico. *Marine Pollution Bulletin*, *36*(1), 65-75.

Paramananthan, S. (2000). *Soils of Malaysia: Their characteristics and identification Vol. 1*. Kuala Lumpur: Academy of Sciences Malaysia.

Parnell, P. E. (2003). The effects of sewage discharge on water quality and phytoplankton of Hawai'ian coastal waters. *Marine environmental research*, *55*(4), 293-311.

Peech, H. M. (1965). "Hydrogen-ion Activity" In *Method of Soil Analysis, Part 2. Eds. Black C. A., Evan D. D., Ensminger L. E., White J. L., Clark F.E. and Dinauer R.C. Madison, Wisconsin: American society of Agronomy*, pp 914 – 926.

Peech, H. M. (1965). "Hydrogen-ion Activity" In *Method of Soil Analysis, Part 2. Eds. Black C. A., Evan D. D., Ensminger L. E., White J. L., Clark F.E. and Dinauer R.C. Madison, Wisconsin: American society of Agronomy*, pp 914 – 926.

Peech, H. M. (1965). "Hydrogen-ion Activity" In *Method of Soil Analysis, Part 2. Eds. Black C. A., Evan D. D., Ensminger L. E., White J. L., Clark F.E. and Dinauer R.C. Madison, Wisconsin: American society of Agronomy*, pp 914 – 926.

Pinckney, J. L., Paerl, H. W., Tester, P., & Richardson, T. L. (2001). The role of nutrient loading and eutrophication in estuarine ecology. *Environmental Health Perspectives*, *109*(Suppl 5), 699.

Qayyum, M. F., Ashraf, I., Abid, M., & Steffens, D. (2015). Effect of biochar, lime, and compost application on phosphorus adsorption in a Ferralsol. *Journal of Plant Nutrition and Soil Science*, *178*(4), 576-581.

Rabai, K. A., Ahmed, O. H., & Kasim, S. (2013). Use of formulated nitrogen, phosphorus, and potassium compound fertilizerusing clinoptilolite zeolite in maize (Zea mays L.) cultivation. *Emirates Journal of Food and Agriculture*, 713-722.

Rahman, Z. A., Gikonyo, E., Silek, B., Goh, K. J., and Soltangheis, A. (2014). Evaluation of phosphate rock sources and rate of application on oil palm yield grown on peat soils of Sarawak, Malaysia. *Journal of Agronomy*, 13: 12-22. DOI: 10.3923/ja.2014.12.22.

Redin, M., Recous, S., Aita, C., Dietrich, G., Skolaude, A. C., Ludke, W. H., Schmatz, R. and Giacomini, S.J. (2014). How the chemical composition and heterogeneity of crop residue mixtures decomposing at the soil surface affects C and N mineralization. *Soil biology and biochemistry*, *78*, 65-75.

Reopanichkul, P., Carter, R. W., Worachananant, S., & Crossland, C. J. (2010). Wastewater discharge degrades coastal waters and reef communities in southern Thailand. *Marine environmental research*, *69*(5), 287-296.

Richardson, A. E. (2001). Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Functional Plant Biology*, *28*(9), 897-906.

Richardson, A. E. (2001). Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Functional Plant Biology*, *28*(9), 897-906.

Ritchie, G. S. P. (1994). Role of dissolution and precipitation of minerals in controlling soluble aluminium in acidic soils. *Advances in Agronomy*, 53, 47-83.

Rondon, M. A., Molina, D., Hurtado, M., Ramirez, J., Lehmann, J., Major, J., and Amezquita, E. (2006). Enhancing the productivity of crops and grasses while reducing greenhouse gas emissions through bio-char amendments to unfertile tropical soils.

Rowell, D. L. (1994). Soil science: methods and applications. Department of Soil Science, University of Reading.

Saeed, I., Abbasi, M. K., & Kazmi, M. (2001). Response of Maize (Zea mays, L.) to NP Fertilization under Agro-climatic Conditions of Rawalakot Azad Jammu and Kashmir. *Pakistan Journal of Biological Sciences*, *4*(8), 949-952.

Sanchez, P. A. (1976). Properties and management of soils in the tropics. John Wiley, New York. *Properties and management of soils in the tropics. John Wiley, New York.*

Sattell, R., Dick, R., Hemphill, D. D., Selker, J. S., Brandi-Dohrn, F. M., Minchew, H., Hess, M., Sandeno, J., and Kaufman, S. M. (1999). *Nitrogen scavenging: using cover crops to reduce nitrate leaching in western Oregon*. Corvallis, Or.: Extension Service, Oregon State University.

Schachtman, D. P., Reid, R. J., & Ayling, S. M. (1998). Phosphorus uptake by plants: from soil to cell. *Plant physiology*, *116*(2), 447-453.

Schachtman, D. P., Reid, R. J., & Ayling, S. M. (1998). Phosphorus uptake by plants: from soil to cell. *Plant physiology*, *116*(2), 447-453.

Schneider, F., & Haderlein, S. B. (2016). Potential effects of biochar on the availability of phosphorus—mechanistic insights. *Geoderma*, *277*, 83-90.

Scholz, R. W., Ulrich, A. E., Eilittä, M., & Roy, A. (2013). Sustainable use of phosphorus: a finite resource. *Science of the Total Environment*, *461*, 799-803.

Scott, H. L., Ponsonby, D., & Atkinson, C. J. (2014). Biochar: an improver of nutrient and soil water availability-what is the evidence?. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *9*(19), 1-19.

Shamshuddin, J., Che Fauziah, I., & Bell, L. C. (2009). Effect of dolomitic limestone and gypsum applications on soil solution properties and yield of corn and groundnut grown on ultisols. *Malay. J. Soil Sci*, *13*, 1-12.

Shamshuddin, J., Fauziah, I. C., & Sharifuddin, H. A. H. (1991). Effects of limestone and gypsum application to a Malaysian Ultisol on soil solution composition and yields of maize and groundnut. *Plant and Soil*, *134*(1), 45-52.

Sharpley, A., Foy, B., & Withers, P. (2000). Practical and innovative measures for the control of agricultural phosphorus losses to water: an overview. *Journal of Environmental Quality*, *29*(1), 1-9.

Shehu, H. E., Ezekiel, C. S., Kwari, J. D., & Sandabe, M. K. (2010). Agronomic efficiency of N , P and K fertilization in sesame (*Sesamum indicum*) in Mubi Region, Adamawa State, Nigeria. *Nature and Science, 8*, 257–260.

Shultz, S. (2008). Corn. *Journal of Agricultural & Food Information*, *9*(2), 101-114.

Smit, A. L., Bindraban, P. S., Schröder, J. J., Conijn, J. G., & Van der Meer, H. G. (2009). *Phosphorus in agriculture: global resoources, trends and developments: report to the Steering Committee Technology Assessment of the Ministery of Agriculture, Nature and Food Quality, The Netherlands, and in collaboration with the Nutrient Flow Task Group (NFTG), supported by DPRN (Development Policy review Network)*(No. 282). Plant Research International.

Smith, V. H., Tilman, G. D., & Nekola, J. C. (1999). Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental pollution*, *100*(1-3), 179-196.

Sohi, S. P., Krull, E., Lopez-Capel, E., & Bol, R. (2010). A review of biochar and its use and function in soil. In *Advances in agronomy* (Vol. 105, pp. 47-82). Academic Press.

Soil Survey Staff. (2014). Keys to Soil Taxonomy, 12th edn. Washington, DC: USDA-Natural Resources Conservation Service.

Sonmez, S., Buyuktas, D., Okturen, F., & Citak, S. (2008). Assessment of different soil to water ratios (1: 1, 1: 2.5, 1: 5) in soil salinity studies. *Geoderma*, *144*(1-2), 361-369.

Soo, C. L., Ling, T. Y., Lee, N., & Apun, K. (2016). Assessment of the characteristic of nutrients, total metals, and fecal coliform in Sibu Laut River, Sarawak, Malaysia. *Applied Water Science*, *6*(1), 77-96.

Spokas, K. A., Koskinen, W. C., Baker, J. M., & Reicosky, D. C. (2009). Impacts of woodchip biochar additions on greenhouse gas production and sorption/degradation of two herbicides in a Minnesota soil. *Chemosphere*, *77*(4), 574-581.

Stevenson, F. J., Stevenson, E. J., & Cole, M. A. (1999). *Cycles of soils: carbon, nitrogen, phosphorus, sulfur, micronutrients*. John Wiley & Sons.

Streubel, J. D., Collins, H. P., Garcia-Perez, M., Tarara, J., Granatstein, D., & Kruger, C. E. (2011). Influence of contrasting biochar types on five soils at increasing rates of application. *Soil Science Society of America Journal*, *75*(4), 1402-1413.

Stribley, D. P., Tinker, P. B., & Snellgrove, R. C. (1980). Effect of vesicular-arbuscular mycorrhizal fungi on the relations of plant growth, internal phosphorus concentration and soil phosphate analyses. *Journal of Soil Science*, *31*(4), 655-672.

Susilawati, K., Osumanu, H. A., Nik, M., Mohd, K. Y., and Mohamadu, B. J. (2009). Effect of organic based N fertilizer on dry matter (*Zea mays* L.), ammonium and nitrate recovery in an acid soil of Sarawak, Malaysia. *American Journal of Applied Sciences*, *6*(7), 1289-1294. DOI: 10.3844/ajassp.2009.1289.1294.

Tang, C., Sparling, G. P., McLay, C. D. A., and Raphael, C. (1999). Effect of short-term legume residue decomposition on soil acidity. *Australian Journal of Soil Research*, 37(3), 561-573.

Tang, Y., Zhang, H., Schroder, J. L., Payton, M. E., and Zhou, D. (2007). Animal manure reduces aluminium toxicity in an acid soil. *Soil Science Society of America Journal*, *71*(6), 1699-1707. DOI: 10.2136/sssaj2007.0008.

Tang, Y., Zhang, H., Schroder, J. L., Payton, M. E., and Zhou, D. (2007). Animal manure reduces aluminium toxicity in an acid soil. *Soil Science Society of America Journal*, *71*(6), 1699-1707. DOI: 10.2136/sssaj2007.0008.

Theodorou, M. E., & Plaxton, W. C. (1993). Metabolic adaptations of plant respiration to nutritional phosphate deprivation. *Plant physiology*, *101*(2), 339-344.

Torrent, J. (1997). Interactions between phosphate and iron oxide. *Advances in Geoecology*, *30*, 321-344.

Troeh, F. R., & Thompson, L. M. (2005). *Soils and soil fertility* (Vol. 489). Ames: Blackwell.

Ulén, B., von Brömssen, C., Johansson, G., Torstensson, G., and Forsberg, L. S. (2012). Trends in nutrient concentrations in drainage water from single fields under ordinary cultivation. *Agriculture, ecosystems and environment*, *151*, 61-69. DOI: 10.1016/j.agee.2012.02.005.

Ulén, B., von Brömssen, C., Johansson, G., Torstensson, G., and Forsberg, L. S. (2012). Trends in nutrient concentrations in drainage water from single fields under ordinary cultivation. *Agriculture, ecosystems and environment*, *151*, 61-69. DOI: 10.1016/j.agee.2012.02.005.

Ulyett, J., Sakrabani, R., Kibblewhite, M., & Hann, M. (2014). Impact of biochar addition on water retention, nitrification and carbon dioxide evolution from two sandy loam soils. *European Journal of Soil Science*, *65*(1), 96-104.

Uzoma, K. C., Inoue, M., Andry, H., Fujimaki, H., Zahoor, A., & Nishihara, E. (2011). Effect of cow manure biochar on maize productivity under sandy soil condition. *Soil use and management*, *27*(2), 205-212.

Van Zwieten, L., Kimber, S., Morris, S., Chan, K. Y., Downie, A., Rust, J., ... & Cowie, A. (2010). Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant and soil*, *327*(1-2), 235-246.

Vassilev, N., Martos, E., Mendes, G., Martos, V., and Vassileva, M. (2013). Biochar of animal origin: a sustainable solution to the global problem of high- grade rock phosphate scarcity?. *Journal of the Science of Food and Agriculture*, *93*(8), 1799-1804.

Veneklaas, E. J., Lambers, H., Bragg, J., Finnegan, P. M., Lovelock, C. E., Plaxton, W. C., ... & Raven, J. A. (2012). Opportunities for improving phosphorus- use efficiency in crop plants. *New Phytologist*, *195*(2), 306-320.

Von Uexküll, H. R., & Mutert, E. (1995). Global extent, development and economic impact of acid soils. *Plant and soil*, *171*(1), 1-15.

Von Uexküll, H. R., & Mutert, E. (1995). Global extent, development and economic impact of acid soils. *Plant and soil*, *171*(1), 1-15.

Wang, T., Camps-Arbestain, M., Hedley, M., & Bishop, P. (2012). Predicting phosphorus bioavailability from high-ash biochars. *Plant and Soil*, *357*(1-2), 173-187.

Wang, Y. T., Zhang, T. Q., O'Halloran, I. P., Tan, C. S., Hu, Q. C., & Reid, D. K. (2012). Soil tests as risk indicators for leaching of dissolved phosphorus from agricultural soils in Ontario. *Soil Science Society of America Journal*, *76*(1), 220-229.

Xu, G., Sun, J., Shao, H., & Chang, S. X. (2014). Biochar had effects on phosphorus sorption and desorption in three soils with differing acidity. *Ecological engineering*, *62*, 54-60.

Xu, G., Wei, L. L., Sun, J. N., Shao, H. B., & Chang, S. X. (2013). What is more important for enhancing nutrient bioavailability with biochar application into a sandy soil: Direct or indirect mechanism?. *Ecological engineering*, *52*, 119-124.

Yamato, M., Okimori, Y., Wibowo, I. F., Anshori, S., and Ogawa, M. (2006). Effects of the application of charred bark of *Acacia mangium* on the yield of maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. *Soil science & plant nutrition*, *52*(4), 489-495. DOI: 10.1111/j.1747-0765.2006.00065.x.

Yang, D. S., Bhattacharjya, D., Song, M. Y., & Yu, J. S. (2014). Highly efficient metal-free phosphorus-doped platelet ordered mesoporous carbon for electrocatalytic oxygen reduction. *Carbon*, *67*, 736-743.

Young, K., Morse, G. K., Scrimshaw, M. D., Kinniburgh, J. H., MacLeod, C. L., & Lester, J. N. (1999). The relation between phosphorus and eutrophication in the Thames catchment, UK. *Science of the Total Environment*, *228*(2-3), 157-183.

Yuan, J. H., & Xu, R. K. (2012). Effects of biochars generated from crop residues on chemical properties of acid soils from tropical and subtropical China. *Soil Research*, *50*(7), 570-578

Yuan, J. H., Xu, R. K., Wang, N. and Li, J. Y. (2011). Amendment of acid soils with crop residues and biochars. *Pedosphere*. 21(3): 302–308.

Yuan, Y., Locke, M. A., Bingner, R. L., & Rebich, R. A. (2013). Phosphorus losses from agricultural watersheds in the Mississippi Delta. *Journal of environmental management*, *115*, 14-20.

Zeng, Z., Li, T. Q., Zhao, F. L., He, Z. L., Zhao, H. P., Yang, X. E., Wang, H.L., Zhao, J. and Rafiq, M.T. (2013). Sorption of ammonium and phosphate from aqueous solution by biochar derived from phytoremediation plants. *Journal of Zhejiang University Science B*, *14*(12), 1152-1161.

Zhang, H., Chen, C., Gray, E. M., Boyd, S. E., Yang, H., & Zhang, D. (2016). Roles of biochar in improving phosphorus availability in soils: a phosphate adsorbent and a source of available phosphorus. *Geoderma*, *276*, 1-6.

Zheng, W., Guo, M., Chow, T., Bennett, D. N., & Rajagopalan, N. (2010). Sorption properties of greenwaste biochar for two triazine pesticides. *Journal of hazardous materials*, *181*(1-3), 121-126.

Zhuan-xi, L., Bo, Z., Jia-liang, T., & Tao, W. (2009). Phosphorus retention capacity of agricultural headwater ditch sediments under alkaline condition in purple soils area, China. *Ecological Engineering*, *35*(1), 57-64.