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NUTRIENT RELEASE FROM RICE AND RUBBER BIOCHAR TABLETS WITH AND WITHOUT EMBEDDED FERTILIZERS

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By

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October 2021

Chair : Prof. Ahmed Osumanu Haruna
Faculty : Agricultural Science and Forestry (Bintulu Campus)

An alternative to agricultural residues management is to convert them to biochar because this organic amendment can act as a superior soil conditioner that improves soil productivity. Nevertheless, the low density of biochar poses a challenge in the handling biochar. Tableting of biochar can mitigate the aforementioned problems associated with biochar. The objectives of this study were to determine the physico-chemical properties, nutrient release and soil ammonia volatilization of biochar tablets with and without embedded fertilizers. The different rates of biochar tablets with and without embedded fertilizers impact on selected soil chemical characteristics and nutrient use efficiency (NUE) of sweet corn (test crop) were also determined. Next planting cycle was conducted to determine the effects of combination biochar and fertilizers with and without tableting on selected soil chemical characteristics and NUE of sweet corn (test crop).

The composition of biochar mixture was 50% charred rice husk, 30% charred rice straw, and 20% charred rubber twigs. The NPK fertilizers used for this study were ammonium sulfate (AS), triple superphosphate (TSP), and muriate of potash (MOP). The biochar tablet (BT) was produced by blending a biochar mixture with starch followed by tableting using a single punch tablet press whereas the fertilizer embedded biochar tablet (BF) was prepared using the same procedure except that NPK fertilizers were added during blending. Similarly, a combination of biochar and NPK without tableting (Biochar + NPK) was prepared. The ratio of biochar to fertilizers mixture used for the BF and Biochar + NPK production was 2:1. Standard procedures were used to characterize BT, BF, Biochar + NPK, and NPK. The nutrient release of the biochar and fertilizers with- and without- tablets were determined using the water

incubation over 30 days. The daily loss ammonia was measured using a closed dynamic air flow system model for 10 days. A pot experiment with six fertilization treatments including control was carried out in an open field located in Perlis, Malaysia to determine the different rates of biochar tablets with- and without embedded fertilizers impact on selected soil chemical characteristics and NUE of the sweet corn (test crop). Sweet corn was cultivated for 53 days (tasselling) and after which the crops were harvested and partitioned into leaves, stems, roots and tassel flowers. The sweet corn plant tissues were analyzed for total C, N, P and K using standard procedures. Soil samples were taken from the pots after the sweet corn plants were harvested and the soil chemical properties were determined. Next planting cycle for the pot experiment with four fertilization treatments including control was conducted to determine effects of the combination biochar and fertilizers with and without tableting on the soil chemical characteristics and NUE of the sweet corn. The procedures used were the same as those used in the previous experiment.

Tableting the biochar produced increased the densities of BT (0.70 g cm^{-3}) and BF (0.90 g cm^{-3}). Higher density of BF can ease its handling and storage challenges. The blending of NPK fertilizers with the biochar produced, regardless of with and without tableting significantly increased the concentrations of N, P, K, and Ca, which are essential elements required for successful plant growth, development, and reproduction. The presence of NH bend (1614.26 cm^{-1}) in highly densified BF suggests that the nutrient compounds in BF is more stable against degradation and leaching. The water soluble nutrient release increased in the order of BT < BF < Biochar + NPK < NPK. However, combination of biochar and fertilizers regardless of with and without tableting increased soil ammonia volatilization relative to the NPK fertilizers. The first corn planting cycle demonstrated that co-application of biochar and fertilizers increased soil total C, N, but soil electrical conductivity reduced. Fertilizers only had the lowest effect on the total NUE of the sweet corn. Higher biochar tablet rate and lower rate of fertilizers increased the efficiency of the fertilizers used in the first corn planting cycle. The beneficial effects of tableting the combined use of biochar and NPK on the sweet corn plants' NUE were more evident in the second planting cycle. The findings suggest that the BF can slowly release embedded nutrients in synchrony with optimum nutrient uptake by the sweet corn. Therefore, transforming fertilizer embedded in biochar into tablet is recommended for sweet corn production following a long-term field study to confirm the findings of this pot study.

Keywords: Biochar; Tableting; Nutrient use efficiency; Ammonia volatilization; Tasseling; Binding

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

PENGURAIAN NUTRIEN DARIPADA TABLET BIO-ARANG PADI DAN GETAH YANG TERSISIP DENGAN- DAN TANPA- BAJA

Oleh

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Kaedah alternatif mengendalikan sisa pertanian adalah sisa pertanian ditukarkan ke bio-arang dimana bio-arang boleh bertindak sebagai perapi tanah yang mampu meningkatkan kesuburan tanah. Namun demikian, ketumpatan bio-arang yang rendah telah menyukarkan proses pengendalian, pengangkutan dan penyimpanan. Kaedah menghasilkan bio-arang dalam bentuk tablet mampu meningkatkan kecekapan pengendalian. Objektif kajian ini adalah untuk menentukan sifat kimia, fizikal, kadar penguraian nutrien dan volatilisasi amonia tanah dari tablet bio-arang yang dicampurkan dengan baja dan tanpa baja. Kadar penggunaan yang berbeza dan keberkesanan tablet bio-arang yang dicampurkan dengan baja dan tanpa baja ke atas ciri-ciri kimia tanah serta kecekapan penguraian nutrien pada tanaman jagung manis (tanaman ujian) juga ditentukan. Kitar tanaman yang seterusnya dijalankan untuk menentukan keberkesanan produk hasil pemampatan antara bio-arang dan baja serta produk tanpa pemampatan ke atas ciri-ciri kimia tanah dan kecekapan pengambilan nutrien jagung manis (tanaman ujian).

Antara komposisi campuran bio-arang termasuk sekam padi bakar 50%, jerami padi bakar 30% dan ranting getah bakar 20%. Baja NPK yang digunakan untuk kajian ini adalah ammonium sulfat (AS), triple superphosphate (TSP) dan muriate of potash (MOP). Tablet bio-arang (BT) dihasilkan daripada campuran bio-arang dengan kanji diikuti dengan pemampatan menggunakan pemampat tablet tunggal manakala tablet sebatian bio-arang dan baja (BF) dihasilkan dengan menggunakan prosedur yang sama kecuali baja NPK telah dimasukkan semasa pengadunan. Satu lagi produk telah dihasilkan dengan gabungan bio-

arang dan NPK tanpa pemampatan (Biochar + NPK). Nisbah campuran bio-arang ke baja yang digunakan untuk produk BF dan Biochar + NPK adalah 2:1. Prosedur standard telah diikuti untuk menganalisis ciri-ciri hasil produk BT, BF, Biochar + NPK dan NPK. Kaedah inkubasi air selama 30 hari telah dipraktikkan untuk mengenalpasti kadar penguraian nutrien antara produk tablet baja dan tanpa baja yang disalut dengan bio-arang sementara kadar pengewapan gas amonia telah diukur setiap hari bagi tempoh 10 hari dengan menggunakan model sistem aliran udara dinamik yang tertutup. Satu ekperimen merangkumi enam rawatan baja termasuk kawalan telah dijalankan menggunakan pasu dengan konsep terbuka bagi menentukan kadar penggunaan yang berbeza dan keberkesanan tablet bio-arang dicampurkan dengan baja dan tanpa baja ke atas ciri-ciri kimia tanah serta kecekapan penggunaan nutrien pada tanaman jagung manis (tanaman ujian) . Tanaman jagung manis telah ditanam selama 53 hari dan dituai. Sampel tisu pokok jagung telah dihantar untuk analisis jumlah unsur C, N, P dan K. Sementara itu, sampel tanah juga diambil selepas tanaman dituai bagi menentukan sifat kimianya. Ekperimen pasu yang kitaran kedua seterusnya dijalankan merangkumi empat rawatan baja termasuk kawalan bagi menentukan keberkesanan antara produk hasil pemampatan dan tanpa pemampatan ke atas ciri-ciri kimia tanah dan kecekapan penggunaan nutrien pokok jagung manis. Prosedur yang sama seperti eksperimen sebelumnya digunakan untuk menuai pokok jagung manis dan menganalisis ciri-ciri kimia pada sampel tisu tanaman dan tanah.

Kajian menunjukkan proses pemampatan mampu meningkatkan ketumpatan BT (0.70 g cm^{-3}) dan BF (0.90 g cm^{-3}) yang memudahkan proses pengendalian dan penyimpanan. Pengadunan antara baja NPK dan bio-arang sama ada dalam bentuk tablet atau bukan telah menunjukkan peningkatan kadar N, P, K dan Ca. Sebatian nutrien dalam BF adalah lebih stabil dari segi degrasi dan larut lesap dengan kewujudan unsur NH (1614.26 cm^{-1}) yang terikat dalam BF yang mampat. Turutan kadar peningkatan penguraian nutrien larut air adalah BT < BF < Biochar + NPK < NPK. Kajian menunjukkan peningkatan kadar pengewapan gas amonia pada produk kombinasi bio-arang dan baja berbanding dengan baja NPK. Eksperimen menanam jagung kitaran pertama menunjukkan bahawa penggunaan bersama bio-arang dan baja meningkatkan jumlah karbon dan nitrogen dalam tanah, tetapi mengurangkan kekonduksian elektrik tanah. Rawatan baja sahaja telah mencatat kecekapan pengambilan nutrien yang paling rendah pada pokok jagung manis. Ekperimen menanam jagung kitaran pertama telah menunjukkan penggunaan tablet bio-arang yang lebih tinggi dan kadar baja yang rendah mampu meningkatkan kecekapan pengambilan baja. Ekperimen menanam jagung kitaran kedua telah menunjukkan sekali lagi bahawa kecekapan pengambilan nutrien yang lebih tinggi dengan menggunakan BF. Hasil kajian menunjukkan bahawa baja BF dapat menguraikan nutrien secara perlahan-lahan secara serentak dengan pengambilan nutrien optimum oleh jagung manis. Maka, penggunaan tablet baja dan biochar yang dimampatkan adalah disyorkan serta diikuti kajian eksperimen ladang yang jangka panjang untuk mengesahkan hasil kajian eksperimen pasu ini.

Kata kunci: Bio-arang; Pemampatan; Kerbekesanan penggunaan nutrien; Volatilisasi ammonia; Pembungaan; Pengikatan

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I certify that a Thesis Examination Committee has met on 5 October 2021 to conduct the final examination of Lee Yit Leng on her thesis entitled "Nutrient Release from Rice and Rubber Biochar Tablets With and Without Embedded Fertilizers" 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

AS	Ammonium sulfate
TSP	Triple superphosphate
MOP	Muriate of potash
BT	Biochar tablets
BF	Fertilizers embedded with biochar tablet
Biochar + NPK	Combination of biochar and NPK without tableting
NPK	Nitrogen, phosphorus and potassium fertilizers
FTIR	Fourier Transform Infrared Spectroscopy
SPAD	Soil plant analysis development
GHG	Greenhouse gases
CO_2	Carbon dioxide
CO	Carbon monoxide
SOC	Soil organic carbon
CH_4	Methane
EC	Electrical conductivity
Na	Sodium
S	Sulfur
CEC	Cation exchange capacity
min	Minutes
BD	Bulk density
BET	Brunauer-Emmet-Teller
Fe	Iron
Zn	Zinc
Cu	Copper

Mn	Manganese
Cd	Cadmium
Se	Selenium
NUE	Nutrient use efficiency
NO_3^-	Nitrate
PO_4^{3-}	Phosphate
N_2O	Nitrous oxide
EFP	Empty fruit bunch
OPF	Oil palm frond
HCl	Hydrochloric acid
HNO_3	Nitric acid
KCl	Potassium chloride
MgO	Magnesium oxide
$NaHCO_3$	Sodium bicarbonate
NaOH	Sodium hydroxide
ICP-OES	Inductively couple plasma optical emission spectrometer
AAS	Atomic absorption spectrophotometer
AA	Autoanalyzer
K_2SO_4	Potassium sulfate
ANOVA	Analysis of variance
SAS	Statistical analysis system
NH_4F	Ammonium fluoride

CHAPTER 1

INTRODUCTION

1.1 Research background

Large amount of agricultural residues such as rice husk, rice straw, green leaves, and rubber tree twigs are generated annually nationwide but they are barely reutilized. Malaysia is one of the Asean countries which largely produces oil palm (*Elaeis guineensis*), rubber (*Hevea brasiliensis*) and rice (*Oryza Sativa*). The growth rate of rubber cultivation in Malaysia is 15 m^3 ha^{-1} $year^{-1}$ (Ratnasingam et al., 2015), whereas rice cultivation covers approximately 688,770 ha (Agrofood Statistics, 2016). Approximately, four million tons of rice straw was produced in 2015 and 0.48 million tons of rice husk is produced annually in Malaysia (Shafie et al., 2014). The rubber tree twigs and rice residues generated from rubber pruning and rice production, respectively are commonly left to decompose in situ or burned in the field with consequent negative impact with environment, particularly greenhouse gas (GHG) emissions (Rondon et al., 2007). Therefore, these low cost renewable agricultural residues should be reused and valorized.

An alternative of agricultural residues management is to convert the rice residues and rubber tree twigs to biochar at the same time harvesting the energy (in the form of heat) produced during pyrolysis. Biochar is rich in aromatic carbon (C) which can act as a C sink. Nevertheless, higher ash and lower C content are reported in rice residue biochar compared with biochar derived from other feedstocks at the same pyrolysis conditions (Asadi et al., 2021). Singh et al. (2021) reported that the potential use of rice residue biochar on salinity stress reduction and crop yield improvement. During the charring process, the carboxylic acid and hydroxyl groups are formed on the carbonaceous surface of biochar (Sonkar and Sarkar, 2019). High large surface area during pyrolysis for the reactivity of biochar because it enables them to retain a significant amount of water and nutrients (Saxena et al., 2014; Vaughn et al., 2013). Although lignocellulosic biomass-derived biochar is a good soil amendment, mineral fertilizers are often required to sustain high agricultural yield. Some literature has suggested that biochar mixed with nitrogen (N), phosphorus (P), and potassium (K) to produce NPK fertilizers with bentonite clay as a binding agent increased rice yields by 15%–30% compared with chemical fertilizers applied at 500 kg ha^{-1} (Qian et al., 2014; Joseph et al., 2013). In another study, the N use efficiency of plant increased by biochar-amended from 7% to 261% compared with non-amended soils (Cao et al., 2019). Combination of biochar and fertilizers application can reduce wastage of chemical fertilizers and their accompanied environmental pollution.

Nitrogen is often the most limiting nutrient yet this nutrient is needed by crops in large amount for their growth and development and because of these reasons, N fertilizer is in high demand (Heffer and Prud'homme, 2015). However, excessive use of N fertilizer can lead to loss of N *via* soil ammonia (NH_3) volatilization and runoff and leaching during intense rainfall (Wang et al., 2018; Hou et al., 2018). Excessive N loss decreases nutrient use efficiency (NUE) and yield of crops. There are inconsistent data on the impacts of biochar addition on the soil NH_3 volatilization. Biochar application increased NH_3 volatilization in saline soil, as salt ions constrained NH_3/ammonium (NH_4^+) adsorption capacity of biochar (Zhu et al., 2020). Higher rates of biochar increased soil NH_3 volatilization (Sun et al., 2017). In contrast, the using 5% biochar significantly reduced NH_3 volatilization in non-saline soils (Mandal et al., 2016). The potential of biochar to decrease NH_3 volatilization depends on its pyrolysis condition, biochar's pH, soil pH, soil moisture content, and soil temperature (Mandal et al., 2018).

However, biochar with high ash and low density makes it difficult in the handling process during soil application, transportation and storage. Husk and Major (2008) reported that approximately 25% of biochar are lost during application in the field. High rainfall can increase the loss of biochar by 20% and 53% through surface runoff (Major et al., 2010). Alternatively, tableting of biochar can impart the dense, uniform and durable properties, which reduce the loss of biochar in agricultural systems to offset the cost of handling, transporting, and storing biochar (Reza et al., 2012). The tableting is an important process by which the density of biomass is significantly increased (Soleimani et al., 2017). Tableting is one of the densification processes and its outcome depends on the initial raw material characteristics and the equipment used. Binder and temperature used for pellets production determine the nutrient release rate of biochar pellets (Kim et al., 2014). Fertilizer-embedded biochar pellets which are dried at 180 °C with increasing lignin content from 10 to 30 wt.% has a slower K and P release than pellets that are dried at 105 °C (Kim et al., 2014).

1.2 Problem statements

Although biochar tablet with embedded fertilizers is deemed as a potential cost-effective slow-release fertilizer in soils, there is lack of information on nutrient release and soil NH_3 volatilization from rice residues mix together rubber tree twigs-derived biochar tablet with embedded NPK fertilizers (BF). Also, there is dearth of information on the effect rates of BF on the growth and NUE of several crops. Several literature reported the effects of co-application biochar and fertilizers on the NUE of plants. Yet the effects of the combination of biochar and fertilizers with and without tableting on nutrient release and NUE are unknown. Therefore, this study was carried out to produce a BF as a more ecologically sound slow-release fertilizer. The biochar derived from thermal decomposition of rice straw, husk, and rubber tree twigs was blended with commercial fertilizers after which underwent with or without tableting process. This novel BF was evaluated for the quality in term of its ability to release nutrient and its effects on

NUE of plants relative to those without tableting and conventional fertilizers. We hypothesized that less voids in the BF is assumed to release the nutrients slowly and lower soil NH_3 volatilization ascribed to the close connection between the biochar particles and fertilizers. Minimal nutrient and NH_3 loss by applying the BF might have improved the soil quality and plant NUE.

1.3 General objectives

The objectives of this study were to determine the nutrient release and soil ammonia volatilization of blended biochar and fertilizer with- and without tableting which eventually impact on the soil chemical characteristics and NUE of sweet corn (test crop).

1.4 Significance of Study

Application of biochar and fertilizers is widely adopted to improve soil quality and plant yield performance but biochar is light density and hence incur much loss of nutrient during the handling and soil application. This study will provide information regarding which blended of biochar and fertilizers into tablet or without tablet is effective on the controlled nutrient release, soil NH_3 volatilization and eventually increases the plant NUE. Such information is valuable in the design of improved fertilizer application strategies. The results of the study will be of great benefit for the farmers to minimize the use of chemical fertilizers by blending fertilizers and biochar into tablet to improve soil quality and crop productivity while reducing negative impact to the environment.

REFERENCES

Abe, H., Katayama, A., Sah, B. P., Toriu, T., Sammy, S., Pheach, P, Adams, M. A. and Grierson, P. (2007). Potential for Rural Electrification Based on Biomass Gasification in Cambodia. Biomass and Bioenergy, 31: 656–664.

Adapa, P. K., Schoenau, G. J., Tabil, L. G., Sokhansanj, S. and Crerar, B. J. 2003. Pelleting of fractionated alfalfa products. In ASABE paper no. 036069, ASABE, St. Joseph, MI.

Adhikari, S., Gascó, G., Méndez, A., Surapaneni, A., Jegatheesan, J., Shah, K. and Paz-Ferreiro, J. (2019). Influence of pyrolysis parameters on phosphorus fractions of biosolids derived biochar. Science of The Total Environment, 695: 133846.

Agegnehu, G., Srivastava, A. K. and Bird, M. I. (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: A review. Applied Soil Ecology, 119: 156-170.

Agegnehu, G., Bass, A. M., Nelson, P. N., Muirhead, B., Wright, G. and Bird, M. I. (2015). Biochar and biochar-compost as soil amendments: effects on peanut yield, soil properties and greenhouse gas emissions in tropical North Queensland, Australia. Agriculture, Ecosystems and Environment, 213: 72-85.

Agrofood statistics. (2016). Ministry of Agriculture and Agro-Based Industry Malaysia. pp. 1-170.

Ahmad, M., Usman, A. R. A., Al-Faraj, A. S., Ahmad, M., Sallam, A. and Al-Wabel, M. I. (2018). Phosphorus-loaded biochar changes soil heavy metals availability and uptake potential of maize (Zea mays L.) plants. Chemosphere, 194: 327-339.

Ahmad, M., Ahmad, M., Usman, A. R. A., Al-Faraj, A. S., Abduljabbar, A., Ok, Y. S. and Al-Wabel, M. I. (2017). Date palm waste-derived biochar composites with silica and zeolite: synthesis, characterization and implication for carbon stability and recalcitrant potential. Environmental Geochemistry and Health. pp. 1-18.

Alemi, H., Kianmehr, M. H. and Borghaee, A. M. (2010). Effect of pellet processing of fertilizer on slow-release nitrogen in soil. Asian Journal of Plant Sciences, 9: 74-80.

Allen Dray, Jr. F., Center, T. D. and Mattison, E. D. (2012). In situ estimates of waterhyacinth leaf tissue nitrogen using a SPAD-502 chlorophyll meter. Aquatic Botany, 100: 72-75.

Aller, M. F. (2016). Biochar properties: transport, fate, and impact. Critical Reviews in Environmental Science and Technology, 46(14–15): 1183-1296.

Amin, A. E. A. Z. and Eissa, M. A. (2017). Biochar effects on nitrogen and phosphorus use efficiencies of zucchini plants grown in a calcareous sandy soil. Journal of Soil Science and Plant Nutrition, 17(4): 912–921.

Andreasen, C., Kemezys, A. H. and Muller, R. (2014). The effect of fertilizer level and foliar-applied calcium on seed production and germination of gerbera hybrid. American Society of Horticultural Science, 49(5): 538–543.

Anugoolprasert, O., Kinoshita, S., Naito, H., Shimizu, M., Ehara, H. (2012). Effect of low pH on the growth, physiological characteristics and nutrient absorption of sago palm in a hydroponic system. Plant Production Science, 15: 125–131.

Anwari, G., Mandozai, A. and Feng, J. (2020). Effects of biochar amendment on soil problems and improving rice production under salinity conditions. Advanced Journal of Graduate Research, 7(1): 45-63.

Arif, M., Ali, A., Umair, M., Munsif, F., Ali, K., Inamullah, Saleem, M. and Ayub, G. (2012). Effect of biochar, FYM and mineral nitrogen alone and in combination on yield and yield components of maize. Sarhad Journal of Agriculture, 28(2): 191-195.

Asadi, H., Ghorbani, M., Rezaei-Rashti, M., Abrishamkesh, S., Amirahmadi, E., Chengrong, C. and Gorji, M. (2021). Application of rice husk biochar for achieving sustainable agriculture and environment. Rice Science, 28(4): 325–343.

Bandala, E. R. and Berli, M. (2019). Engineered nanomaterials (ENMs) and their role at the nexus of food, energy, and water. Materials Science for Energy Technologies, 2(1): 29-40.

Basao, A. S., Miguez, F. E., Laird, D. A., Horton, R. and Westgate, M. (2013). Assessing potential of biochar for increasing water-holding capacity of sandy soils. Global Change Biology Bioenergy, 5: 132–143.

Bashir, M. A., Naveed, M., Ahmad, Z., Gao, B., Mustafa, A. and Nunez-Delgado, A. (2020). Combined application of biochar and sulfur regulated growth, physiological, antioxidant responses and Cr removal capacity of maize (Zea mays L.) in tannery polluted soils. Journal of Environmental Management, 259: 110051.

Bazargan, A., Rough, S. L. and McKay, G. (2014). Compaction of palm kernel shell biochars for application as solid fuel. Biomass Bioenergy, 70: 489–497.

Begum, K., Sikder, A. H. F., Khanom, S., Hossain, M. F. and Parveen, Z. (2015). Nutrient uptake by plants from different land types of madhupur soils. Bangladesh Journal of Scientific Research, 28(2): 113-121.

Belda, R. M., Lidon, A. and Fornes, F. (2016). Biochars and hydrochars as substrate constituents for soilless growth of myrtle and mastic. Industrial Crops and Products, 94: 132-142.

Bernhart, M. and Fasina, O. O. (2009). Moisture effect on the storage, handling and flow properties of poultry litter. Waste Management, 29: 1392–1398.

Bista, D. R., Heckathorn, S. A., Jayawardena, D. M., Mishra, S. and Boldt, J. K. (2018). Effects of Drought on Nutrient Uptake and the Levels of Nutrient-Uptake Proteins in Roots of Drought-Sensitive and -Tolerant Grasses. Plants, 7(2): 28.

Bowden-Green, B. and Briens, L. (2016). An investigation of drum granulation of biochar powder. Powder technology, 288: 249-254.

Bouyoucos, G. J. (1962). Hydrometer meter improved for making particle size analysis of soils. Agronomy Journal, 54: 464–465.

Brassard, P., Godbout, S., Pelletier, F., Raghavan, V. and Palacios, J. H. (2018). Pyrolysis of switchgrass in an auger reactor for biochar production: A greenhouse gas and energy impacts assessment. Biomass and Bioenergy, 116: 99-105.

Bray, R. H. and Kurtz, L. (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59: 39-46.

Brewer, C. E., Chuang, V. J., Masiello, C. A., Gonnermann, H., Gao, X., Dugan, B., Driver, L. E., Panzacchi, P., Zygourakis, K. and Davies, C. A. (2014). New approaches to measuring biochar density and porosity. Biomass and Bioenergy, 66: 176-185.

Bruun, E. W., Müller-Stöver, D., Ambus, P. and Hauggaard-Nielsen, H. (2011). Application of biochar to soil and N_2O emissions: potential effects of blending fast-pyrolysis biochar with anaerobically digested slurry. European Journal of Soil Science, 62(4): 581-589.

Budai, A., Wang, L., Gronli, M., Strand, L. T., Antal, M. J., Abiven, S., Dieguez-Alonso, A., Anca-Couce, A. and Rasse D. P. (2014). Surface properties and chemical composition of corncob and miscanthus biochars: effects of production temperature and method. Journal of Agricultural and Food Chemistry, 62(17): 3791–3799.

Buss, W., Graham, M. C., Shepherd, J. G. and Masek, O. (2016). Suitability of marginal biomass-derived biochars for soil amendment. Science of the Total Environment, 547: 314-322.

Caban, M., Folentarska, A., Lis, H., Kobylis, P., Bielicka-Giełdon, A., Kumirska, J., Ciesielski, W. and Stepnowski, P. (2020). Chemosphere, 248: 125976.

Cantrell, K. B., Hunt, P. G., Uchimiya, M., Novak, J. M. and Ro. K. S. (2012). Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. Bioresource Technology, 107: 419–428.

Cao, H., Ning, L., Xun, M., Feng, F., Li, P., Yue, S., Song, J., Zhang, W. and Yang H. (2019). Biochar can increase nitrogen use efficiency of Malus hupehensis by modulating nitrate reduction of soil and root. Applied Soil Ecology, 135, 25-32.

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

Cha, J. S., Park, S. H., Jung, S. C., Ryu, C., Jeon, J. K., Sin, M. C. and Park, Y. K. (2016). Production and utilization of biochar: A review. Journal of Industrial and Engineering Chemisry, 40: 1-15.

Chan, Y. H., Cheah, K. W., How, B. S., Loy, A. C. M., Shahbaz, M., Singh, H. K. G., Yusuf, N. R., Ahmad Shuhaili, A. F., Yusup, S., Abd Karim Ghani, W. A. W., Rambli, J., Kansha, Y., Lam, H. L., Hong, B. H. and Ngan, S. L. (2019). An overview of biomass thermochemical conversion technologies in Malaysia. Science of the Total Environment, 680: 105-123.

Chatterjee, R., Sajjadi, B., Chen, W., Mattern, D. L., Hammer, N., Raman, V. and Dorris, A. (2020). Effect of Pyrolysis Temperature on Physico-chemical Properties and Acoustic-Based Amination of Biochar for Efficient CO_2 Adsorption. Frontiers in Energy Research, 8: 85.

Chathurika, J. A. S., Kumaragamage, D., Zvomuya, F., Akinremi, O. O., Flaten, D. N., Indraratne, S. P. and Dandeniya, W. S. (2016). Woodchip biochar with or without synthetic fertilizers affects soil properties and available phosphorus in two alkaline, chernozemic soils. Canadian Journal of Soil Science, 96: 472–484.

Chen, S., Qi, G., Ma, G. and Zhao, X. (2020). Biochar amendment controlled bacterial wilt through changing soil chemical properties and microbial community. Microbiological Research, 231: 126373.

Chen, X., Liu, M., Kuzyakov, Y., Li, W., Liu, J., Jiang, C., Wu, M. and Li, Z. (2018). Incorporation of rice straw carbon into dissolved organic matter and microbial biomass along a 100-year paddy soil chronosequence. Applied Soil Ecology, 130: 84-90.

Chen, J., Li, S., Liang, C. F., Xu, Q. F., Li, Y. C., Qin, H. and Fuhrman, J. J. (2017). Response of microbial community structure and function to short-term biochar amendment in an intensively managed bamboo (Phyllostachys praecox) plantation soil: Effect of particle size and addition rate. Science of the Total Environment, 574: 24-33.

Chen, W. F., Zhang W. M. and Meng, J. (2013). Advances and prospects in research of biochar utilization in agriculture. Scientia Agricultura Sinica, 46(16): 3324-3333.

Chen, T., Wu C., Liu R., Fei W. and Liu S. (2011a). Effect of hot vapor filtration on the characterization of bio-oil from rice husks with fast pyrolysis in a fluidized-bed reactor. Bioresource Technology, 102(10): 6178-6185.

Chen, B., Chen, Z. and Lv, S. (2011b). A novel magnetic biochar efficiently sorbs organic pollutants and phosphate. Bioresource Technology, 102: 716–723.

Cheng, H., Jones, D. L., Hill, P., Bastami, M. S., Tu, C. L. (2017). Influence of biochar produced from different pyrolysis temperature on nutrient retention and leaching. Archives of Agronomy and Soil Science. pp. 1-11.

Cheng, C. H., Lin, T. P., Lehmann, J., Fang, L. J., Yang, Y. W., Menyailo, O. V., Chang, K. H. and Lai, J. S. (2014). Sorption properties for black carbon (wood char) after long term exposure in soils. Organic Geochemistry, 70: 53–61.

Chien, S. H., Gearhart, M. M. and Villagarcia S. (2011). Comparison of ammonium sulfate with other nitrogen and sulfur fertilizers in increasing crop production and minimizing environmental impact: A review. Soil Science, 176(7): 327-335.

Chintala, R., Schumacher, T. E., Mcdonald, L. M., Clay, D. E., Malo, D. D., Papiernik, S. K., Clay, S. A. and Julson, J. L. (2014). Phosphorus sorption and availability from biochars and soil/biochar mixtures. Clean - Soil, Air, Water, 42(5): 626-634.

Claosten, N., Samsuri, A. W., Ahmad husni, M. H.. Mohd Amran, M. S. (2014). Effects of pyrolysis temperature on the physicochemical properties of empty fruit bunch and rice husk biochars. Waste Management Research, 32: 331–339.

Clough, T. J. and Condron, L. M. (2010). Biochar and the nitrogen cycle. Journal of Environmental Quality, 39: 1218–1223.

Coggon, M. M., Veres, P. R., Yuan, B., Koss, A., Warneke, C., Gilman, J. B., Lerner B. M., Peischl, J., Aikin, K. C., Stockwell, C. E., Hatch, L. E., Ryerson, T. B., Roberts, J. M., Yokelson, R. J. and de Gouw, J. A. (2016). Emissions of nitrogen-containing organic compounds from the burning of herbaceous and arboraceous biomass: Fuel composition dependence and the variability of commonly used nitrile tracers. Geophysical Research Letters, 43: 9903–9912.

Colantoni, A., Evic, N., Lord, R., Retschitzegger, S., Proto, A. R., Gallucci, F. and Monarca, D. (2016). Characterization of biochars produced from pyrolysis of pelletized agricultural residues. Renewable and Sustainable Energy Reviews, 64: 187-194.

Colwell, J. D. (1963). The estimation of phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. Australian Journal of Experimental Agriculture and Animal Husbandry, 3: 190–197.

Connor, D. J., Loomis, R. S. and Cassman, K. G. (2011). Crop Ecology: Productivity and Management in Agricultural Systems. Cambridge University Press. pp. 1-570.

Cottenie, A. (1980). Soil testing and plant testing as a basis of fertilizer recommendation. FAO Soil Bulletin, 38: 3-70.

Cornelissen, G., Jubaedah, Nurida, N. L., Hale, S. E., Martinsen, V., Silvani, L. and Mulder J. (2018). Fading positive effect of biochar on crop yield and soil acidity during five growth seasons in an Indonesian Ultisol. Science of The Total Environment, 634: 561-568.

Cosentino, I., Restuccia, L., Ferro, G. A. and Tulliani, J. (2019). Type of materials, pyrolysis conditions, carbon content and size dimensions: The parameters that influence the mechanical properties of biochar cement-based composites. Theoretical and Applied Fracture Mechanics, 103: 102261.

de Vasconcelos, A. C. F. (2020). Biochar Effects on Amelioration of Adverse Salinity Effects in Soils. In Applications of Biochar for Environmental Safety; Abdelhafez, A.A., Abbas, M.H.H., Eds.; IntechOpen: London, UK.

Dhamodaran, A. and Afzal, M. T. (2012). Compression and Springback Properties of Hardwood and Softwwod Pellets. BioResources, 7(3): 4362-4376.

Ding, F., Van Zwieten, L., Zhang, W., Weng, Z., Shi, S., Wang, J. and Meng, J. (2018). A meta-analysis and critical evaluation of influencing factors on soil carbon priming following biochar amendment. Journal of Soils and Sediments, 18: 1507–1517.

Ding, Y., Liu, Y., Liu, S., Huang, X., Li, Z., Tan, X., Zeng, G. and Zhou, L. (2017). Potential Benefits of Biochar in Agricultural Soils: A Review. Pedosphere, 27(4): 645–661.

Dodson, R. J. (2011). Wheat Straw Ash and Its Use as a Silica Source, Ph.D thesis, University of York Chemistry, UK. pp. 1-302.

Dong, X., Singh, B. P., Li, G., Lin, Q. and Zhao, X. (2019). Biochar increased field soil inorganic carbon content five years after application. Soil and Tillage Research, 186: 36-41.

Dou, L., Komatsuzaki, M. and Nakagawa, M. (2012). Effects of Biochar, Mokusakueki and Bokashi application on soil nutrients, yields and qualities of sweet potato. International Research Journal of Agricultural Science and Soil Science, 2(8): 318-327.

Dumroese, R. K., Heiskanen, J., Englund, K. and Tervahauta, A. (2011). Pelleted biochar: Chemical and physical properties show potential use as a substrate in container nurseries. Biomass and Bioenergy, 35(5): 2018-2027.

Dunisch, O., Lima, V. C., Seehann, G., Donath, J., Montoia, V. R. and Schwarz, T. (2007). Retention properties of wood residues and their potential for soil amelioration. Wood Science and Technology, 41(2): 169–189.

Dunnigan, L., Ashman, P. J., Zhang, X., Kwong, C. W. (2018). Production of biochar from rice husk: Particulate emissions from the combustion of raw pyrolysis volatiles. Journal of Cleaner Production, 170: 1639–1645.

El-Ramady, H. R., Alshaal, T. A., Amer, M., Domokos-Szabolcsy, E., Elhawat, N., Prokisch, J. and Fari, M. (2014). Soil Quality and Plant Nutrition. Sustainable Agriculture Reviews, 14: 345–447.

El Sharkawi, H. M., Tojo, S., Chosa, T., Malhat, F. M. and Youssef, A. M. (2018). Biochar-ammonium phosphate as an uncoated-slow-release fertilizer in sandy soil. Biomass and Bioenergy, 117: 154-160.

Esteban, R., Ariz, I., Cruz, C. and Moran, J. F. (2016). Review: mechanisms of ammonium toxicity and the quest for tolerance. Plant Science, 248: 92-101.

ETP (2013). Economic Transformation Programme 2013 Annual Report. Kuala Lumpur.

Fageria, N. K., Santos, A. B. D. and Moraes, M. F. (2010). Influence of Urea and Ammonium Sulfate on Soil Acidity Indices in Lowland Rice Production. Communications in Soil Science and Plant Analysis, 41(13): 1565-1575.

Fan, R., Zhang, B., Li, J., Zhang, Z. and Liang, A. (2020). Straw-derived biochar mitigates CO_2 emission through changes in soil pore structure in a wheat-rice rotation system. Chemosphere, 243: 125329.

Feng, J., Cheng, R., Anwari, Q. A., Yan, Q. G., Li, Y. G., Li, J. B., Dong, H., Xian, Q. Z., Xu, L. and Xi, W. S. (2018). Effects of biochar on sodium ion accumulation, yield and quality of rice in saline-sodic soil of the West of Songnen Plain, Northeast China. Plant, Soil and Environment, 64(12): 612–18.

Ferreira, E. C., Neto, J. A. G., Milori, D. M., Ferreira, E. J. and Anzano J. M. (2015). Laser-induced breakdown spectroscopy: extending its application to soil pH measurements. Spectrochimica Acta Part B: Atomic Spectroscopy, 110: 96-99.

Fidel, R. B., Laird, D. A. and Spokas, K. A. (2018). Sorption of ammonium and nitrate to biochars is electrostatic and pH-dependent. Scientific Reports, 8(1).

Fiorentini, M., Zenobi, S., Giorgini, E., Basili, D., Conti, C., Pro, C., Monaci, E. and Orsini, R. (2019). Nitrogen and chlorophyll status determination in

durum wheat as influenced by fertilization and soil management: preliminary results. PLoS One, 14(11): e0225126.

Fiorentino, N., Sánchez-Monedero, M. A., Lehmann, J., Enders, A., Fagnano, M. and Cayuela, M. L. (2019). Interactive priming of soil N transformations from combining biochar and urea inputs: a 15N isotope tracer study. Soil Biology Biochemistry, 131: 166-175.

Fornari, A. J., Caires, E. F., Bini, A. R., Haliski, A., Tzaskos, L. and Jolis, H. A. W. (2020). Nitrogen fertilization and potassium requirement for cereal crops under acontinuous no-till system. Pedosphere, 30(6): 747-758.

Fu, P., Hu, S., Xiang, J., Sun, L., Su, S. and Wang, J. (2012). Evaluation of the porous structure development of chars from pyrolysis of rice straw: Effects of pyrolysis temperature and heating rate. Journal of Analytical Applied Pyrolysis, 98: 177–183.

Gagnon, B., Ziadi, N., Belanger, G. and Parent, G. (2020). Validation and use of critical phosphorus concentration in maize. European Journal of Agronomy, 120: 126147.

Gao, S., DeLuca T. H. and Cleveland, C. C. (2019). Biochar additions alter phosphorus and nitrogen availability in agricultural ecosystems: a meta-analysis. Science of Total Environment, 654: 463-472.

Garcia, R., González-Vázquez, M. P., Rubiera, F., Pevida, C. and Gil, M. V. (2021). Co-pelletization of pine sawdust and refused derived fuel (RDF) to high-quality waste-derived pellets. Journal of Cleaner Production, 129635.

Ge, T. D., Sun, N. B., Bai, L. P., Tong, C. L. and Sui, F. G. (2012). Effects of drought stress on phosphorus and potassiumuptake dynamics in summer maize (Zea mays) throughout the growth cycle. Acta Physiologiae Plantarum, 34: 2179–2186.

Ghani, W. A. W. A. K., Mohd, A., Silva, G. D., Bachmann, R. T., Taufiq-Yap, Y. H., Rashid, U. and Al-Muhtaseb, A. H. (2013). Biochar production from waste rubber-wood-sawdust and its potential use in C sequestration: Chemical and physical characterization. Industrial Crops and Products, 44: 18-24.

Ghorbani, M., Asadi, H. and Abrishamkesh, S. (2019). Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. International Soil and Water Conservation Research, 7(3): 258-265.

Gonzaga, M. I. S., Mackowiak, C. L., Comerford, N. B, Moline, E. F. V., Shirley, J. P. and Guimaraes, D. V. (2017). Pyrolysis methods impact biosolids-derived biochar composition, maize growth and nutrition. Soil and Tillage Research, 165: 59–65.

Greger, M., Landberg, T. and Vaculík, M. (2018) Silicon influence soil availability and accumulation of mineral nutrient in various plant species. Plant, 7(2): 41.

Guerena, D., Lehmann, J., Hanley, K., Enders, A., Hyland, C. and Riha, S. (2013). Nitrogen dynamics following field application of biochar in a temperate North American maize-based production system. Plant and Soil, 365: 239–254.

Guerriero, G, Hausman, J-F. and Legay, S. (2016). Silicon and the plant extracellular matrix. Frontiers in Plant Science, 7: 1–8.

Gura, I. and Mnkeni, P. N. S. (2019). Crop rotation and residue management effects under no till on the soil quality of a Haplic Cambisol in Alice, Eastern Cape, South Africa. Geoderma, 337: 927-934.

Hale, S. E., Nurida, N. L., Jan Mulder, J., Sormo, E., Silvani, L., Abiven, S., Joseph, S., Taherymoosavi, S. and Cornellissen, G. (2020). The effect of biochar, lime and ash on maize yield in a long-term field trial in an Ultisol in the humid tropics. Science of the Total Environment, 719: 137455.

Hale, S. E., Alling, V., Martinsen, V., Mulder, J., Breedveld, G. D. and Cornelissen, G. (2013). The sorption and desorption of phosphate-P, ammonium-N and nitrate-N in cacao shell and corn cob biochars. Chemosphere, 91: 1612–1619.

Halim, S. A. and Swithenbank, J. (2016). Characterisation of Malaysian wood pellets and rubberwood using slow pyrolysis and microwave technology. Journal of Analytical and Applied Pyrolysis, 122: 64-75.

Ham, B., Chen, J., Yan, Y. and Lucas, W. J. (2018). Insights into plant phosphate sensing and signaling. Current Opinion in Biotechnology, 49: 1–9.

Hammond, J., Shackley, S., Sohi, S. and Brownsort, P., 2011. Prospective life cycle carbon abatement for pyrolysis biochar systems in the UK. Energy Policy, 39: 2646-2655.

Hansen, V., Müller-Stöver, D., Ahrenfeldt, J., Holm, J. K., Henriksen, U. B. and Hauggaard- Nielsen, H. (2015). Gasification biochar as a valuable by-product for carbon sequestration and soil amendment. Biomass and Bioenergy, 72: 300–308.

Han, T. U., Kim, Y. M., Watanabe, C., Teramae, N., Park, Y. K., Kim, S. and Lee, Y. (2016). Journal of Industrial and Engineering Chemisry, 32: 345.

Harsono, S. S., Grundman, P., Lau, L. H., Hansen, A., Salleh, M. A. M., Meyer-Aurich A. (2013). Energy balances, greenhouse gas emissions and economics of biochar production from palm oil empty fruit bunches. Resources Conservation and Recycling, 77: 10-15.

Haryati Z., Loh S. K., Kong S. H., Bachmann R. T. (2018). Pilot scale biochar production from palm kernel shell in a fixed bed allothermal reactor. Journal of Oil Palm Research, 30(3): 485-494.

Harun, N. and Afzal, M. (2016). Effect of Particle Size on Mechanical Properties of Pellets Made from Biomass Blends. Procedia Engineering, 148: 93-99.

Hauer-Jakli, M. and Trankner, M. (2019). Critical Leaf Magnesium Thresholds and the Impact of Magnesium on Plant Growth and Photo-Oxidative Defense: A Systematic Review and Meta-Analysis from 70 Years of Research. Frontiers in Plant Science, 10: 1-15.

He, L., Zhao, J., Yang, S., Zhou, H., Wang, S., Zhao, X. and Xing, G. 2020. Successive biochar amendment improves soil productivity and aggregate microstructure of a red soil in a five-year wheat-millet rotation pot trial. Geoderma, 376: 114570.

He, L., Zhao, H., Wang, S. and Xing, G. (2016). The effects of rice-straw biochar addition on nitrification activity and nitrous oxide emissions in two Oxisols. Soil and Tillage Research, 164: 52-62.

Heffer, P. and Prud'homme, M. (2015). Fertilizer Outlook 2015–2019. 83rd IFA Annual Conference, Istanbul, Turkey, 25–27 May 2015.

Hezam Saeed, A. A., Harun, N. Y. and Nasef, M. M. (2019). Physicochemical characterization of different agricultural residues in malaysia for bio char production. International Journal of Biotechnology Research and Development, 2(1): 10-22.

Hong, C. O., Owens, V. N., Kim, Y. G., Lee, S. M., Park, H. C., Kim, K. K., Son, H. J., Suh, J. M., Lee, Y. B. and Kim, P. J. (2014). Comparative effect of two different types of phosphate on cadmium uptake by radish (Raphanus sativa L.) grown in arable soil affected by mine activity. Communication Soil Science and Plant Analysis, 45: 1133-1148.

Hou, X., Zhan, X., Zhou, F., Yan, X., Gu, B., Reis, S., Wu, Y., Liu, H., Piao, S. and Tang, Y. (2018). Detection and attribution of nitrogen runoff trend in China's croplands. Environmental Pollution, 234: 270-278.

Hu, Q., Yang, H. P., Yao, D. D., Zhu, D. C., Wang, X. H., Shao, J. and Chen, H. P. (2016). The densification of bio-char: Effect of pyrolysis temperature on the qualities of pellets. Bioresource Technology, 200: 521-527.

Hu, Q., Yang, H., Yao, D., Zhu, D., Wang, X., Shao, J. and Chen, H. (2015). The densification of bio-char: Effect of pyrolysis temperature on the qualities of pellets. Bioresource Technology, 200: 521-527.

Huang, J., Duan, Y., Xu, M., Zhai, L., Zhang, X., Wang, B., Zhang, Y., Gao, S. and Sun, N. (2017). Nitrogen mobility, ammonia volatilization, and estimated leaching loss from long-term manure incorporation in red soil. Journal of Integrative Agriculture, 16(9): 2082–2092.

Husk, B. and Major, J. (2008). Commercial Scale Agricultural Biochar Field Trial in Quebec, Canada, Over Two Years: Effects of Biochar on Soil Fertility, Biology, Crop Productivity and Quality. Blue Leaf, Quebec, Canada.

International Plant Nutrition Institute (IPNI). (2016). Nitrogen Notes: Ammonia Volatilization, Bulletin #6. Available from http://www.ipni.net/publication/nitrogen-en. nsf/0/B219184650778DB985257DD60005826A /$FILE/NitrogenNotes-EN-6.pdf.

Ioras, F., Ratnasingam, J., Ramasamy, G., Kaner, J. and Wenming, L. (2012). Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 40: 317.

Iqbal, H., Garcia-Perez, M. and Flury, M. (2015). Effect of biochar on leaching of organic carbon, nitrogen, and phosphorus from compost in bioretention systems. Science of the Total Environment, 521: 37–45.

Ishii, K. and Furuichi, T. (2014). Influence of moisture content, particle size and forming temperature on productivity and quality of rice straw pellets. Waste management, 34(12): 2621-2626.

Ismail, C. H., Shajarutulwardah, M. Y., Ahmad Arif, I., Shahida, H., Mohamad Najib, M. Y. and Helda, S. (2013). Keperluan pembajaan baka padi berhasil tinggi. Persidangan Padi Kebangsaan 2013. Seberang Jaya, Pulau Pinang. 10-12 Disember.

Iyobe, T., Asada, T., Kawata, K. and Oikawa, K. (2004). Comparison of removal efficiencies for ammonia and amine gases between woody charcoal and activated carbon. Journal of Health Sciences, 50(2): 148-153.

Janczak, D., Malinska, K., Czekala, W., Caceres, R., Lewicki, A. and Dach, J. (2017). Biochar to reduce ammonia emissions in gaseous and liquid phase during composting of poultry manure with wheat straw. Waste Management, 66: 36-45.

Jay, C. N., Fitzgerald, J. D., Hipps, N. A. and Atkinson, C. J. (2015). Why short-term biochar application has no yield benefits: evidence from three field-grown crops. Soil Use and Management, 31: 241-250.

Jeong, C. Y., Dodla, S. K. and Wang, J. J. (2016). Fundamental and molecular composition characteristics of biochars produced from sugarcane and rice crop residues and by-products. Chemosphere, 142: 4-13.

Jezek, M., Geilfus, C. M., Bayer, A., Mühling, K. H., and Struik, P. C. (2015). Photosynthetic capacity, nutrient status, and growth of maize (Zea mays L.) upon $MgSO_4$ leaf-application. Frontiers in Plant Science, 5: 1–10.

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

Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M. A. and Sonoki, T. (2014). Physical and chemical characterization of biochars derived from different agricultural residues. Biogeosciences, 11: 6613–6621.

Joseph S. D., Camps-Arbestain, M., Lin, Y., Munroe, P., Chia, C. H., Hook, J., Zwieten, L.V., Kimber, S., Cowie, A., Singh, B. P., Lehmann, J., Foidl, N., Smernik, R. J. and Amonette, J. E. (2010). An investigation into the reactions of biochar in soil. Australian Journal of Soil Research, 48: 501-515.

Joseph, S., Graber, E. R., Chia, C., Munroe, P., Donne, S., Thomas, T., Nielsen, S., Marjo, C., Rutlidge, H., Pan, G. X., Li, L., Taylor, P., Rawal, A. and Hook, J. (2013). Shifting paradigms: development of high-efficiency biochar fertilizers based on nano-structures and soluble components. Carbon Management, 4: 323–343.

Jusoh, M. L. C., Manaf, L. A. and Latiff, P. A. (2013). Composting of rice straw with effective microorganisms (EM) and its influence on compost quality. Iranian Journal of Environmental Health Science and Engineering, 10(1): 1-9.

Kaliyan, N. and Morey, R. V. (2009). Densification characteristics of corn stover and switchgrass. Transactions of the ASABE, 52: 907-920.

Kamara, A., Kamara, H. S. and Kamara, M. S. (2015). Effect of rice straw biochar on soil quality and the early growth and biomass yield of two rice varieties. Agricultural Sciences, 6: 798-806.

Kammann, C. I., Schmidt, H. P., Messerschmidt, N., Linsel, S., Steffens, D., Müller, C., Koyro, H. W., Conte, P. and Stephen, J. (2015). Plant growth improvement mediated by nitrate capture in co-composted biochar. Scientific Report, 5: 11080.

Kaniapan, S., Hassan, S., Ya, H., Patma Nesan, K. and Azeem, M. (2021). The utilisation of palm oil and oil palm residues and the related challenges as a sustainable alternative in biofuel, bioenergy, and transportation Sector: A review. Sustainability, 13: 3110.

Karaosmanoglu, F., Isigigurergudenler, A. and Sever A. (2000). Biochar from the straw-stalk of rapeseed plant. Energy and Fuels, 14: 336-339.

Karim, A. A., Kumar, M., Mohapatra, S., Singh, S. K. (2019). Nutrient rich biomass and effluent sludge wastes co-utilization for production of biochar fertilizer through different thermal treatments. Journal of Cleaner Production, 228: 570-579.

Keeney, D. R. and Nelson, D. W. (1982). Nitrogen-inorganic forms. In, Method of Soil Analysis, Part 2 (2nd ed), Page AL, Keeney DR, Baker DE, Miller RH, Ellis R, Rhoades JD(eds.). Agronomy Monographs, 9. ASA and SSSA, Madison, Wisconsin.

Keiluweit, M., Nico, P. S., Johnson, M. G. and Kleber, M. (2010). Dynamic molecular structure of plant biomass-derived black carbon (biochar). Environmental Science and Technology, 44: 1247-1253.

Khanif Y. M. (1992). Ammonia Volatilization from Malaysian Soils Following Application of Urea. Pertanika, 15(2): 115-120.

Kim, P., Hensley, D. and Labbe, N. (2014). Nutrient release from switchgrass-derived biochar pellets embedded with fertilizers. Geoderma, 234-234: 341-351.

Kirsten, C., Lenz, V., Schroder, H. and Repke, J. (2016). Hay pellets — The influence of particle size reduction on their physical–mechanical quality and energy demand during production. Fuel Processing Technology, 148: 163-174.

Kizito, S., Luo, H., Lu, J., Bah, H., Dong, R. and Wu S. (2019). Role of Nutrient-Enriched Biochar as a Soil Amendment during Maize Growth: Exploring Practical Alternatives to Recycle Agricultural Residuals and to Reduce Chemical Fertilizer Demand. Sustainability, 11: 1-22.

Klasson, K. T., Uchimiya, M. and Lima I. M. (2014). Uncovering surface area and micropores in almond shell biochars by rainwater wash. Chemosphere, 111: 129-134.

Kocsis, T., Kotroczo, Z., Kardos, L. and Biro, B. (2020). Optimization of increasing biochar doses with soil–plant–microbial functioning and nutrient uptake of maize. Environmental Technology & Innovation, 20: 101191.

Kong, L., Tian, S., Li, Z., Luo, R., Chen, D. and Tu, Y. (2013). Conversion of recycled sawdust into high HHV and low NOx emission bio-char pellets using lignin and calcium hydroxide blended binders. Renewable Energy, 60: 559–565.

Kuppusamy S., Thavamani P., Megharaj M., Venkateswarlu K., Naidu R. (2016). Agronomic and remedial benefits and risks of applying biochar to soil: Current knowledge and future research directions. Environmental International, 87: 1-12.

Kwak, J. H., Islam, M. S., Wang, S., Messele, S.A., Naeth, M. A., El-Din, M. G. and Chang, S. X. (2019). Biochar properties and lead (II) adsorption capacity depend on feedstock type, pyrolysis temperature, and steam activation. Chemosphere, 231: 393-404.

Labbe, R., Paczkowski, S., Knappe, V., Russ, M., Wohler, M. and Pelz, S. (2020). Effect of feedstock particle size distribution and feedstock moisture content on pellet production efficiency, pellet quality, transport and combustion emissions. Fuel, 263: 116662.

Laird, D., Fleming, P., Wang, B., Horton, R. and Karlen D. (2010). Biochar impact on nutrient leaching from a Midwestern agricultural soil. Geoderma, 158: 436-442.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. Geoderma, 123: 1–22.

Lan, W. and Mingzhu, L. (2008). Preparation and Properties of Chitosan-Coated NPK Compound Fertilizer with Controlled-Release and Water-Retention. Carbohydrate Polymers, 72(2): 240-247.

Lee, E. H., Park, R., Kim, H., Park, S. H., Jung, S. C., Jeon, J. K., Kim, S. C. and Park, Y. K. (2016). Journal of Industrial and Engineering Chemisry, 37: 18

Lee, Y. L., Ahmed, O. H., Wahid, S. A., AB Aziz, Z. F. 2019. Characterization of tablets made from mixture of charred agricultural residues with and without embedded fertilizer. Acta Technological Agriculture, 22(3): 70-74.

Lehmann, J., daSilva, J. P. Jr., Steiner, C., Nehls, T., Zech, W. and Glaser, B. (2003). Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol in the Central Amazon basin: Fertiliser, manure and charcoal amendments. Plant and Soil, 249: 343–357.

Leng, L. Y., Ahmed, O. H., Samsuri, A. W., Norawanis, A. R., Zulkeple, N. N., Ismail, R. I, Makhtar, N. (2019). IOP Conference Series: Materials Science and Engineering, 551(1): 012104.

Leng, L. Y., Husni, M. H. A, Samsuri, A. W. (2013). Stability of pineapple leaf residue chars generated by controlled combustion and by field burning in tropical peat. Clean-Soil Air Water, 41: 1–9.

Leng, L. Y., Husni, M. H. A. and Samsuri, A. W. (2011). Comparison of the carbon-sequestering abilities of pineapple leaf residue chars produced by controlled combustion and by field burning. Bioresource Technology, 102: 10759–10762.

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

Li, H., Li, Y., Xu, Y. and Lu, X. (2020). Biochar phosphorus fertilizer effects on soil phosphorus availability. Chemosphere, 244: 125471.

Li, Z. C., Song, Z. L., Singh, B. P. and Wang, H. L. (2019). The impact of crop residue biochars on silicon and nutrient cycles in croplands. Science of the Total Environment, 659: 673–680.

Li, S., Barreto, V., Li, R., Chen, G. and Hsieh Y. P. (2018). Nitrogen retention of biochar derived from different feedstocks at variable pyrolysis temperatures. Journal of Analytical and Applied Pyrolysis, 133: 136-146.

Li, Y., Huang, L., Zhang, H., Wang, M. and Liang, Z. (2017). Assessment of Ammonia Volatilization Losses and Nitrogen Utilization during the Rice Growing Season in Alkaline Salt-Affected Soils. Sustainability, 9: 132.

Li, J. H., Lv, G. H., Bai, W. B., Liu, Q., Zhang, Y. C. and Song J. Q. (2016). Modification and use of biochar from wheat straw (Triticum aestivum L.) for nitrate and phosphate removal from water. Desalination and Water Treatment, 57(10): 4681-4693.

Li, H., Liu, X., Legros, R., Bi, X. T., Jim Lim, C., Sokhansanj, S. (2012). Pelletization of torrefied sawdust and properties of torrefied pellets. Applied Energy, 93: 680–685.

Lima, J. R. D. S., de Moraes Silva, W., de Medeiros E. V., Duda, G. P., Corrêa, M. M., Martins Filho, A. P., Clermont-Dauphin, C., Antonino, A. C. and Hammecker, C. (2018). Effect of biochar on physicochemical properties of a sandy soil and maize growth in a greenhouse experiment. Geoderma, 319: 14–23.

Limvikran, T., Kheoruenromne, I., Suddhiprakarn, A., Prakongkep, N. and Gilkes, R. J. (2018). Dissolution of K, Ca, and P from biochar grains in tropical soils. Geoderma, 312: 139–150.

Lin, F. F., Qiu, L. F., Deng, J. S., Shi, Y. Y., Chen, L. S. and Wang, K. (2010). Investigation of SPAD meter-based indices for estimating rice nitrogen status. Computers and Electronics in Agriculture, 71(1): S60-S65.

Liu, Y., Gao, C., Wang, Y., He, L., Lu, H. and Yang, S. (2020). Vermiculite modification increases carbon retention and stability of rice straw biochar at different carbonization temperatures. Journal of cleaner production, 254: 120111.

Liu, L. Y., Tan, Z. X., Gong, H. B. and Huang, Q. Y. (2019). Migration and transformation mechanisms of nutrient elements (N, P, K) within biochar in straw–biochar–soil–plant systems: a review. ACS Sustainable Chemical & Engineering, 7: 22-32.

Liu, Z., He, T., Cao, T., Yang, T., Men, J. and Chen, W. 2017. Effects of biochar application on nitrogen leaching, ammonia volatilization and nitrogen use efficiency in two distinct soils. Journal of soil science and plant nutrition, 17(2): 515-528.

Long, A., Zhang, J., Yang, L., Ye, X., Lai, N., Tan, L., Lin, T. and Chen, L. (2017). Effects of Low pH on Photosynthesis, Related Physiological Parameters, and Nutrient Profiles of Citrus. Frontiers in Plant Science, 8: 185.

Long, M., Wu, H. H., Smith, M. D., La Pierre, K. J., Lu, X., Zhang, H., Han, X. and Yu, Q. (2016). Nitrogen deposition promotes phosphorus uptake of plants in a semi-arid temperate grassland. Plant and Soil, 408(1-2): 475-484.

Loow Y. L. and Wu, T. Y. (2018). Transformation of oil palm fronds into pentose sugars using copper (II) sulfate pentahydrate with the assistance of chemical additive. Journal of Environmental Management, 216: 192-203.

Lu, H. L., Zhang, W. H., Wang, S. Z., Zhuang, L. W., Yang, Y. X. and Qiu, R. L. (2013). Characterization of sewage sludge-derived biochars from different feedstocks and pyrolysis temperatures. Journal of Analytical and Applied Pyrolysis, 102: 137-143.

Majeed, Z., Ramli, N. K., Mansor, N. and Man, Z. (2015). A comprehensive review on biodegradable polymers and their blends used in controlled-release fertilizer processes. Reviews in Chemical Engineering, 31(1): 69-96.

Major, J., Lehmann, J., Rondon, M. and Goodale, C. (2010). Fate of soil-applied black carbon: downward migration, leaching and soil respiration. Global Change Biology, 16(4): 1366-1379.

Malaysia economics statistics. (2011). Malaysia Economics Statistics. Retrieved 16 Nov 2011, from Department of Statistics, Malaysia. http://www.statistics.gov.my/portal/index.php.

Malaysia Ministry of Plantation Industries & Commodities (MPIC) (2016). http://www.kppk.gov.my/ (Accessed on 17 January 2016).

Mallarino, A. P. (2011). Corn and soybean response to soil pH level and liming. Integrated Crop Management Conference - Iowa State University. pp 93-102.

Maltese, N. E., Maddonni, G. A., Melchiori, R. J. M., Ferreyra, J. M. and Caviglia, O. P. (2020). Crop nitrogen status of early- and late-sown maize at different plant densities. Field Crops Research, 258: 107965.

MRB. (2016). “Natural Rubber Statistics 2016”, http://www.lgm.gov.my/nrstat/nrstats.pdf. (Assessed on 23 April 2020).

Mandal, S., Donner, E., Smith, E., Sarkar, B. and Lombi, E. (2019). Biochar with near-neutral pH reduces ammonia volatilization and improves plant growth in a soil-plant system: A closed chamber experiment. Science of the Total Environment, 697: 134114.

Mandal, S., Donner, E., Vasileiadis, S., Skinner, W., Smith, E. and Lombi, E. (2018). The effect of biochar feedstock, pyrolysis temperature, and application rate on the reduction of ammonia volatilisation from biochar-amended soil. Science of the Total Environment, 627: 942-950.

Mandal, S., Thangarajan, R., Bolan, N. S., Sarkar, B., Khan, N., Yong, S. O., Naidu, R. (2016). Biochar-induced concomitant decrease in ammonia volatilization and increase in nitrogen use efficiency by wheat. Chemosphere, 142: 120-127.

Mani, S., Tabil, L. G. and Sokhansanj, S. (2006). Specific energy requirement for compacting corn stover. Bioresource Technology, 30: 648-654.

Manolikaki, I. I., Mangolis, A. and Diamadopoulos, E. (2016). The impact of biochars prepared from agricultural residues on phosphorus release and availability in two fertile soils. Journal of Environmental Management, 181: 536-543.

Manolikaki, I. I and Diamadopoulos, E. (2020). Agronomic potential of biochar prepared from brewery byproducts. Journal of Environmental Management, 255: 109856.

Martin-Shields, C. P. and Stojetz, W. (2019). Food security and conflict: empirical challenges and future opportunities for research and policy making on food security and conflict. World Development, 119: 150–164.

Martin, A., Belastegui-Macadam, X., Quillere, I., Floriot, M., Valadier, M. H., Pommel, B., Andrieu, B., Donnison, I. and Hirel, B. (2005). Nitrogen management and senescence in two maize hybrids differing in the persistence of leaf greenness: agronomic, physiological and molecular aspects. New Phytologist, 167: 483-492.

Martinez, F., Oliveira, J. A., Calvete, E. O. and Palencia, P. (2017). Influence of growth medium on yield, quality indexes and SPAD values in strawberry plants. Scientia Horticulturae, 217: 17-27.

Matovic, D. (2011). Biochar as a viable carbon sequestration option: global and Canadian perspective. Energy, 36(4): 2011-2016.

Mau, V. and Gross, A. (2018). Energy conversion and gas emissions from production and combustion of poultry-litter-derived hydrochar and biochar. Applied Energy, 213: 510-519.

Mayfield, J. L. and Kelley, W. T. (2012). Blossom-end rot and calcium nutrition of pepper and tomato. Univ. Ga. Ext. Circ., 938.

Mencaroni, M., Dal Ferro, N., Furlanettoa, J., Longoa, M., Lazzarob, B., Sartoric, L., Grantd, B. B., Smithd, W. N., Morari, F. (2021). Identifying N fertilizer management strategies to reduce ammonia volatilization: Towards a site-specific approach. Journal of Environmental Management, 277: 111445.

Mete, F. Z., Mia, S., Dijkstra, F. A., Abuyusuf, M., Hossain, A. S. M. I. (2015). Synergistic effects of biochar and NPK fertilizer on soybean yield in an alkaline soil. Pedosphere, 25: 713–719.

Morali, U., Yavuzel, N. and Sensoz, S. (2016). Pyrolysis of hornbeam (Carpinus betulus L.) sawdust: Characterization of bio-oil and bio-char. Bioresource Technology, 221: 682-685.

MRB (2014). Malaysian Rubber Board: Natural Rubber Statistic 2014. Malaysian Rubber Board, Kuala Lumpur, Malaysia.

Mukherjee, A., Zimmerman, A. R. and Harris, W. (2011). Surface chemistry variations among a series of laboratory-produced biochars. Geoderma, 163: 247-255.

Muller, J. (2020). Production of fertilizer in Malaysia 2013-2019. Statista 2020.

Mulvaney, R. L. (1996). Nitrogen-Inorganic Forms. In D.L. Sparks, A.L. Page, P.A. Helmke and R.H. Loeppert (Eds.), Methods of Soil Analysis Part 3—Chemical Methods (pp. 1123–1184). Madison: the Soil Science Society of America, Inc., American Society of Agronomy, Inc.

Muramoto, J., Goto, I. and Ninaki, M. (1992). Application of inductively coupled atomic emission spectroscopy to soil analysis. Part. 6. Rapid analysis of exchangeable cations and cation exchange capacity by a shaking extraction method. Japanese Journal of Soil Science Plant Nutrition, 63: 210-218.

Murphy, J. and Riley, J. (1962). A modified single solution for the determination of phosphate in natural waters. Analytica Chimica Acta, 27: 31–36.

Nartey, O. D. and Zhao, B. 2014. Biochar Preparation, Characterization, and Adsorptive Capacity and Its Effect on Bioavailability of Contaminants: An Overview. Advances in Materials Science and Engineering. pp. 1-12.

Ndirangu, S. M., Liu, Y., Xu, K. and Song, S. (2019). Risk Evaluation of Pyrolyzed Biochar from Multiple Wastes. Journal of Chemistry, 2019: 1-28.

Ndzana, G. M., Huang, L., Zhang, Z, Zhu, J., Liu, F. and Bhattacharyya, R. (2019). The transformation of clay minerals in the particle size fractions of two soils from different latitude in China. Catena, 175: 317-328.

Nelson, N. O., Agudelo, S. C., Yuan, W., Gan, J. (2011). Nitrogen and phosphorus availability in biochar-amended soils. Soil Science, 176(5): 218-226.

Nguyen, T. T. N., Xu, C. Y., Tahmasbian, I., Che, R. X., Xu, Z. H., Zhou, X. H., Wallace, H. M. and Bai, H. S. (2017). Effects of biochar on soil available inorganic nitrogen: a review and meta-analysis. Geoderma, 288: 79–96.

Novak, J. M., Johnson, M. G. and Spokas, K. A. (2018). Concentration and release of phosphorus and potassium from lignocellulosic- and manure-based biochars for fertilizer reuse. Frontiers in Sustainable Food Systems, 2(54): 1-9.

Novak, J. M., Lima, I., Xing, B., Gaskin, J. W., Steiner, C., Das, K. C., Ahmedna, M., Rehrah, D., Watts, Donald W., Busscher, W. J. and Schomberg, H. (2009). Characterization of designer biochar produced at different temperatures and their effects on a Loamy Sand. Annals of Environmental Science, 3: 195–206.

Nur, M., Islami, T., Handayanto, E., Nugroho, W. and Utomo, W. (2014). The use of biochar fortified compost on calcareous soil of East Nusa Tenggara,

Indonesia: 2. Effect on the yield of maize (Zea mays L) and phosphate absorption/ American-Eurasian Journal of Sustainable Agriculture. pp. 105-112.

Obernberger, I. and Thek, G. (2009). Wood pellet production costs under Austrian framework conditions. In: Proceedings of the 17th European Biomass Conference & Exhibition, Hamburg, Germany, pp. 2129-2137, ETA-Renewable Energies (Ed.), Italy.

Obernberger, I. and Thek, G. (2004). Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behavior. Biomass Bioenergy, 27: 653–669.

O'Connor, D., Peng, T., Li, G., Wang, S., Duan, L., Mulder, J., Cornelissen, G., Cheng, Z., Yang, S. and Hou, D. (2018). Sulfur-modified rice husk biochar: A green method for the remediation of mercury contaminated soil. Science of the Total Environment, 621: 819–826.

Oladele, S. O. (2019). Changes in physicochemical properties and quality index of an Alfisol after three years of rice husk biochar amendment in rainfed rice – Maize cropping sequence. Geoderma, 353: 359-371.

Oladele, S., Adeyemo, A., Awodun, M., Ajayi, A. and Fasina, A. (2019). Effects of biochar and nitrogen fertilizer on soil physicochemical properties, nitrogen use efficiency and upland rice (Oryza sativa) yield grown on an Alfisol in Southwestern Nigeria. International Journal of Recycling Organic Waste in Agriculture, 8: 295–308.

Omondi, M. O., Xia, X., Nahayo, A., Liu, X., Korai, P. K. and Pan, G. (2016). Quantification of biochar effects on soil hydrological properties using meta-analysis of literature data. Geoderma, 274: 28-34.

Othaman, N. N. C., Isa, M. N. M., Ismail, R. C., Ahmad, M. I. and Hui, C. K. (2020). Factors that affect soil electrical conductivity (EC) based system for smart farming application. AIP Conference Proceedings, 2203: 020055.

Painter, T. J. (2001). Carbohydrate polymers in food preservation: an integrated view of the Maillard reaction with special reference to discoveries of preserved foods in Sphagnum dominated peat bogs. Carbohydrate Polymer, 36: 335-347.

Pampuro, N., Bagagiolo, G., Priarone, P. C. and Cavallo, E. (2017) Effects of pelletizing pressure and the addition of woody bulking agents on the physical and mechanical properties of pellets made from composted pig solid fraction. Powder Technology, 311: 112-119.

Pampuro, N., Facello, A. and Cavallo, E. (2013). Pressure and specific energy requirements for densification of compost derived from swine solid fraction. Spanish Journal of Agricultural Research, 11: 678-684.

Pan, M. Z., Du, J., Gan, X. H. and LV, X. Y. (2016). Distribution and ultrastructure of silica on rice straw surface. Csae, 32: 309-314.

Pandit, N. R., Mulder, J., Hale, S. E., Martinsen, V., Schmidt, H. P. and Cornelissen, G. (2018). Biochar improves maize growth by alleviation of nutrient stress in a moderately acidic low-input Nepalese soil. Science of the Total Environment, 625: 1380-1389.

Pang, W., Hou, D., Wang, H., Sai, S., Wang, B., Ke, J., Wu, G., Li, Q. and Holtzapple, M. (2018). Preparation of Microcapsules of Slow-Release NPK Compound Fertilizer and the Release Characteristics. Journal of the Brazilian Chemical Society, 11(29): 2397-2404.

Panhwar, Q. A., Naher, U. A., Radziah, O., Shamshuddin, J. and Razi, I. M. (2014). Bio-fertilizer, ground magnesium limestone and basalt applications may improve chemical properties of malaysian acid sulfate soils and rice growth. Pedosphere, 24: 827–835.

Partey, S. T., Preziosi, R. F. and Robson, G. D. (2014). Short-term interactive effects of biochar, green manure, and inorganic fertilizer on soil properties and agronomic characteristics of maize. Agricultural Research, 3(2): 128-136.

Paz Ferreiro, J., Pereira De Almeida, V., Cristina Alves, M., Aparecida De Abreu, C., Vieira, S. R. and Vidal Vázquez, E. (2016). Spatial Variability of Soil Organic Matter and Cation Exchange Capacity in an Oxisol under Different Land Uses. Communications in Soil Science and Plant Analysis, 47: 75–89.

Peng, J., Bi, X. T., Lim, C. J., Peng, H., Kim, C. S., Jia, D. and Zuo, H. (2015). Sawdust as an effective binder for making torrefied pellets. Applied Energy, 157: 491–498.

Peng, J., Bi, H., Sokhansanj, S. and Lim, J. (2013). Torrefaction and densification of different species of softwood residues. Fuel, 111: 411–21.

Petchpradab, P., Yoshida, T., Charinpanitkul, T. and Matsumura, Y. (2009). Hydrothermal Pretreatment of Rubber Wood for the Saccharification Process. Industrial and Engineering Chemistry Research, 48: 4587–4591.

Pinho, P., Jokinen, K. and Halonen, L. (2016). The influence of the LED light spectrum on the growth and nutrient uptake of hydroponically grown lettuce. Lighting Research and Technology. pp. 1–16.

Pomares-gracia, F. and Pratt, P. F. (1987). Recovery of 15N-labelled fertilizer from manured and sludge-amended soils. Soil Science Society of America Journal, 42: 717-720.

Prajapati, K. and Modi, H. A. (2012). The importance of potassium in plant growth – a review. Indian Journal of Plant Sciences, 1: 177-186.

Puga, A. P., Grutzmacher, P., Cerri, C. E., Ribeirinho, V. S. and De Andrade, C. A. (2020). Biochar-based nitrogen fertilizers: Greenhouse gas emissions, use efficiency, and maize yield in tropical soils. Science of the Total Environment, 704: 135375.

Qian, L., Chen, L., Joseph, S., Pan, G. X., Li, L. Q., Zheng, J. W., Zhang, X. H., Zheng, J. F., Yu, X. Y. and Wang, J. F. (2014). Biochar compound fertilizer as an option to reach high productivity but low carbon intensity in rice agriculture of China. Carbon Management, 5: 145–154.

Rashti, M. R., Esfandbod, M., Phillips, I. R. and Chen, C. (2019). Rhizosphere management by biochar and leaching improved plant performance in fresh bauxite residue sand. Journal of Cleaner Production, 219: 66-74.

Rasse, D. P., Budai, A., O'Toole, A., Ma, X., Rumpel, C. and Abiven, S. (2017). Persistence in soil of Miscanthus biochar in laboratory and field conditions. PLOS ONE, 12: 0184383.

Ratnasingam, J., Ramas Amy, G., Lim, T. W., Abdul Latib, S. and Neelakandan M. (2015). The prospects of rubberwood biomass energy production in Malaysia. Bioresources, 10(2): 2526–2548.

Rawluk, C. D. L., Grant, C. A. and Racz, G. J. (2001). Ammonia volatilization from soils fertilized with urea and varying rates of urease inhibitor NBPT. Canadian Journal of Soil Science, 81(2): 239-246.

Rayment, G. E and Lyons, D. J (2011). Soil Chemical Methods–Australasia. Melbourne: CSIRO Publishing.

Razaq, M., Zhang, P., Shen, H. and Salahuddin. (2017). Influence of nitrogen and phosphorous on the growth and root morphology of Acer mono. PLOS ONE, 12(2): e0171321.

Rehrah, D., Reddy, M. R., Novak, J. M., Bansode, R. R., Schimmel, K. A., Yu, J., Watts, D. W. and Ahmedna, M. (2014). Production and characterization of biochars from agricultural by-products for use in soil quality enhancement. Journal of Analytical and Applied Pyrolysis, 108: 301-309.

Rentsch, D., Schmidt, S. and Tegeder, M. (2007). Transporters for uptake and allocation of organic nitrogen compounds in plants. FEBS Letters, 581: 2281–2289.

Reza, M. T., Uddin, M. H., Lynam, J. G. and Coronella, C. J. (2014). Engineered pellets from dry torrefied and HTC biochar blends. Biomass and Bioenergy, 63: 229-238.

Reza, M. T., Lynam, J. G., Vasquez, V. R. and Coronella, C. J. (2012). Pelletization of biochar from hydrothermally carbonized wood. Environmental Progress & Sustainable Energy, 31(2): 225–234.

Rezaei, H., Jim Lim, C., Lau, A. and Sokhansanj, S. (2016). Size, shape and flow characterization of ground wood chip and ground wood pellet particles. Powder Technology, 301: 737-746.

Richardson, A. E., Lynch, J. P., Ryan, P. R., Delhaize, P. E., Smith, F. A., Smith, S. E., Harvey, P. R., Ryan, M. H., Veneklaas, E. J., Lambers, H., Oberson, A., Culvenor, R. A. and Simpson, R. J. (2011). Plant and microbial strategies to improve the phosphorus efficiency of agriculture. Plant and Soil, 349: 121–156.

Robredo, A., Pérez-López, U., Miranda-Apodaca, J., Lacuesta, M., Mena-Petite, A. and Muñoz-Rueda, A. (2011). Elevated CO_2 reduces the drought effect on nitrogen metabolism in barley plants during drought and subsequent recovery. Environmental and Experimental Botany, 71: 399–408.

Rondon, M. A., Lehmann, J., Ramírez, J. and Hurtado, M. (2007). Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with bio-char additions. Biology and Fertility of Soils, 43: 699–708.

Roshanravan, B., Soltani, S. M., Rashid, S. A., Mahdavi, F. and Yusop, M. K. (2015). Enhancement of nitrogen release properties of urea–kaolinite fertilizer with chitosan binder. Chemical Speciation & Bioavailability, 27(1): 44-51.

Rosmiza, M. Z., Davies, W. P., Rosniza Aznie, C. R., Mazdi, M., Jabil, M. J. (2014). Farmers' knowledge on potential uses of rice straw: An assessment in MADA and Sekinchan, Malaysia. Malaysian Journal of Society and Space, 10(5): 30-43.

Rowley, M. C., Grand, S. and Verrecchia, E. P. (2018). Calcium-mediated stabilisation of soil organic carbon. Biogeochemistry, 137: 27-49.

Rudolfsson, M., Stelte, W. and Lestander, T. A. (2015). Process optimization of combined biomass torrefaction and pelletization for fuel pellet production – a parametric study. Applied Energy, 140: 378–384.

Rumpel, C., Ba, A., Darboux, F., Chaplot, V. and Planchon, O. (2009). Erosion budget and process selectivity of black carbon at meter scale. Geoderma, 154(1–2): 131-137.

Sabri, M. A. (2009). "Evolution of fertilizer use by crops in Malaysia". Report presented at IFA Crossroads Asia-Pacific 2009, Kota Kinabalu, Malaysia.

Saha, J., Basak, S. S., Gajbhiye, N. A., Kalariya, K. A. and Manivel, P. (2019). Sustainable fertilization through co-application of biochar and chemical fertilizers improves yield, quality of Andrographis paniculate and soil health. Industrial crops and products, 140: 111607.

Sakuraba, Y. and Yanagisawa S. (2018). Light signalling-induced regulation of nutrient acquisition and utilisation in plants. Seminars in Cell and Developmental Biology, 83: 123-132.

Sanaullah, M., Rumpel, C., Charrier, X. and Chabbi A. (2012). How does drought stress influence the decomposition of plant litter with contrasting quality in a grassland ecosystem? Plant and Soil, 352: 277–288.

Sánchez-García, M., Alburquerque, J. A., Sánchez-Monedero, M. A., Roig, A., Cayuela, M. L. (2015). Biochar accelerates organic matter degradation and enhances N mineralization during composting of poultry manure without a relevant impact on gas emissions. Bioresource Technology, 192: 272-279.

Santos, F., Torn, M. S. and Bird, J. A. (2012). Biological degradation of pyrogenic organic matter in temperate forest soils. Soil Biology and Biochemistry, 51: 115-124.

Sarangi, M., Bhattacharyya, S. and Behera, R. C. (2009). Rice effect of temperature on morphology and phase transformations of nanocrystalline silica obtained from rice husk. Phase Transitions, 82(5): 377 – 386.

Sato, M. K., Lima, H. V. D., Costa, A. N., Rodrigues, S., Pedroso, A. J. S., Mai, C. M. B. D. F. (2019). Biochar from Acai agroindustry waste: Study of pyrolysis conditions. Waste Management, 96: 158-167.

Saxena, M., Maity, S. and Sarkar, S. (2014). Carbon nanoparticles in 'biochar' boost wheat (Triticum aestivum) plant growth. RSC Advances, 4: 39948–39954.

Scaglioni, P. T. and Badiale-Furlong, E. (2016). Rice husk as an adsorbent: A new analytical approach to determine aflatoxins in milk. Talanta, 152: 423-431.

Schraml, M., Gutser, R., Maier, H. and Schmidhalter, U. (2016). Ammonia loss from urea in grassland and its mitigation by the new urease inhibitor 2-NPT. Journal of Agricultural Science, 154: 1453-1462.

Seesanong, S., Seangarun, C., Boonchom, B., Laohavisuti, N., Chaiseeda, K. and Boonmee, W. (2021). Composition and Properties of Triple Superphosphate Obtained from Oyster Shells and Various Concentrations of Phosphoric Acid. ACS Omega, 6(34): 22065–22072.

Sha, Z., Li, Q., Lv, T., Misselbrook, T. and Liu, X. (2019). Response of ammonia volatilization to biochar addition: A meta-analysis. Science of the Total Environment, 655: 1387-1396.

Shaaban, A., Se, S. M., Dimin, M. F., Juoi, J. M., Husin, M. H. M. and Mitan, N. M. M. (2014). Influence of heating temperature and holding time on biochars derived from rubber wood sawdust via slow pyrolysis. Journal of Analytical and Applied Pyrolysis, 107: 31-39.

Shafie, S. M., Masjuki, S. H. and Mahlia, T. M. I. (2014). Life cycle assessment of rice straw-based power generation in Malaysia. Energy, 70: 401-410.

Shamshuddin, J., Panhwar, Q. A, Roslan, I., Fauziah, C. I., Naher, U. A. and Hakeem, K. R. (2015). Sustaining Cocoa Production on Oxisols in Malaysia. Crop Production and Global Environmental Issues, 169-180.

Sharma, V. and Sharma, K. N. (2013). Influence of Accompanying Anions on Potassium Retention and Leaching in Potato Growing Alluvial Soils. Pedosphere, 23(4): 464-471.

Shen, J., Tang, H., Liu, J., Wang, C., Li, Y., Ge, T., Jones, D. L. and Wu, J. (2014). Contrasting effects of straw and straw-derived biochar amendments on greenhouse gas emissions within double rice cropping systems. Agriculture, Ecosystems and Environment, 188: 264–274.

Shi, R., Li, J., Ni, N. and Xu, R. (2019). Understanding the biochar's role in ameliorating soil acidity. Journal of Integrative Agriculture, 18(7): 1508-1517.

Shibata, M., Sugihara, S., Mvondo-Ze, A. D., Araki, S. and Funakawa, S. (2017). Nitrogen flux patterns through Oxisols and Ultisols in tropical forests of Cameroon, Central Africa. Soil Science and Plant Nutrition, 63(3): 306-317.

Shin, J., Jang, E., Park, S., Ravidran, B. and Chang, S. W. (2019). Agro-environmental impacts, carbon sequestration and profit analysis of blended biochar pellet application in the paddy soil-water system. Journal of Environmental Management, 244: 92-98.

Shin J. and Park S. (2018). Optimization of Blended Biochar Pellet by the Use of Nutrient Releasing Model. Applied Science, 8: 2274.

Shrestha, L. K., Thapa, M., Shrestha, R. G., Maji, S., Pradhananga, R. R. and Ariga, K. (2019). Rice Husk-Derived High Surface Area Nanoporous Carbon Materials with Excellent Iodine and Methylene Blue Adsorption Properties. Journal of Carbon Research, 5(10): 1-13.

Singh, G., Mavi, M. S., Choudhary, O. P., Gupta, N. and Singh, Y. (2021). Rice straw biochar application to soil irrigated with saline water in a cotton-wheat system improves crop performance and soil functionality in north-west India. Journal of Environmental Management, 295: 113277.

Singh, R., Singh, P., Singh, H. and Raghubanshi. (2019). Impact of sole and combined application of biochar, organic and chemical fertilizers on wheat crop yield and water productivity in a dry tropical agro-ecosystem. Biochar, 1: 229-235.

Singh, R., Camps Arbestain, M. and Lehmann, J. (2017). Biochar: A Guide to Analytical Methods. In CSIRO Publishing, pp. 1–320.

Singh, R., Babu, J. N., Kumar, R., Srivastava, P., Singh, P. and Raghubanshi, A. S. (2015). Multifaceted application of crop residue biochar as a tool for sustainable agriculture: an ecological perspective. Ecological Engineering, 77: 324–347.

Singh, B. P. and Cowie, A. L. (2014). Long-term influence of biochar on native organic carbon mineralisation in a low-carbon clayey soil. Scientific Reports, 4: 3687.

Singh, B. P., Hatton, B. J., Singh, B., Cowie, A. L. and Kathuria, A. (2010). Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils. Journal of Environmental Quality, 39(4): 1224–1235.

Sohi, S., Capel, E. L., Krull, E. and Bol, R. (2010). Biochar, climate change and soil: A review to guide future research. In CSIRO Land Water Science Report; Collingwood, Victoria, Australia. pp. 1–64.

Soleimani, M., Tabil, X. L., Grewal, R. and Tabil, L. G. (2017). Carbohydrates as binders in biomass densification for biochemical and thermochemical processes. Fuel, 193: 134-141.

Song, X., Yang, Y., Zhang, M., Zhang, K. and Wang, D. (2018). Ultrasonic pelleting of torrefied lignocellulosic biomass for bioenergy production. Renewable Energy, 129: 56-62.

Sonkar, S. K. and Sarkar, S. (2019). Prospects of nanocarbons in agriculture. Nanocarbon and its Composites. pp. 287-326.

Spokas, K. A., Cantrell, K. B., Novak, J. M., Archer, D. W., Ippolito, J. A., Collins, H. P., Boateng, A. A., Lima, I. M., Lamb, M. C., McAloon, A. J., Lentz, R. D. and Nichols, K. A. (2012). Biochar: a synthesis of its agronomic impact beyond carbon sequestration. Journal of Environmental Quality, 41: 973-989.

Stelte, W., Sanadi, A. R., Shang, L., Holm, J. K., Ahrenfeldt, J. and Henriksen U. B. (2012). Recent developments in biomass pelletization – a review. BioResources, 7(3): 4451-4490.

Suarez-Abelenda, M., Kaal, J. and McBeath, A. V. (2017). Translating analytical pyrolysis fingerprints to Thermal Stability Indices (TSI) to improve biochar characterization by pyrolysis-GC-MS. Biomass and Bioenergy, 98: 306–320.

Suliman, W., Harsh, J. B., Abu-Lail, N. I., Fortuna, A. M., Dallmayer, I. and Garzia-Perez, M. (2016a). The role of biochar porosity and surface functionality in augmenting hydrologic properties of a sandy soil. Science of Total Environment, 574: 139-147.

Suliman, W., Harsh, J. B., Abu-Lail, N. I., Fortuna, A., Dallmeyer, I. and Garcia-Perez, M. (2016b). Influence of feedstock source and pyrolysis temperature on biochar bulk and surface properties. Biomass and Bioenergy, 84: 37-48.

Sun, H, Min, J, Zhang, H, Feng, Y, Lu, K, Shi, W, Yu, M and Li, X. (2018). Biochar application mode influences nitrogen leaching and NH_3 volatilization losses in a rice paddy soil irrigated with N-rich wastewater. Environmental Technology, 39(16): 2090–2096.

Sun, H., Lu, H., Chu, L., Shao, H. and Shi, W. (2017). Biochar applied with appropriate rates can reduce N leaching, keep N retention and not increase NH_3 volatilization in a coastal saline soil. Science of Total Environment, 575: 820-825.

Tag, A. T., Duman, G., Ucar, S. and Yanik, J. (2016). Effects of feedstock type and pyrolysis temperature on potential applications of biochar. Journal of Analytical and Applied Pyrolysis, 120: 200–206.

Tale, K. S. and Ingole, D. S. (2016). A Review on Role of Physico-Chemical Properties in Soil Quality. Chemical Science Review and Letters, 4(13): 57 – 66.

Tender, C. A. D., Debode, J., Vandecasteele, B., D'Hose, T., Cremelie, P., Haegeman, A., Ruttink, T., Dawyndt, P. and Maes, M. (2016). Biological, physicochemical and plant health responses in lettuce and strawberry in soil or peat amended with biochar. Applied Soil Ecology, 107: 1-12.

Teutscherova, N., Houska, J., Navas, M., Masaguer, A., Benito, M. and Vazquez, E. (2018). Leaching of ammonium and nitrate from Acrisol and Calcisol amended with holm oak biochar: A column study. Geoderma, 323: 136-145.

Thangarajan, R, Bolan, N. S., Kunhikrishnan, A., Wijesekara, H., Xu, Y., Tsang, D. C., Song, H., Ok, Y. S. and Hou, D. (2018). The potential value of biochar in the mitigation of gaseous emission of nitrogen. Science of the Total Environment, 612: 257-268.

The Edge Financial Daily (2012). Retrieved 15 October 2012 from https://www.theedgemarkets.com/article/malaysia-could-tap-fertiliser-market/

Titiladunayo, I. F., McDonald, A. G. and Fapetu, O. P. (2012). Effect of Temperature on Biochar Product Yield from Selected Lignocellulosic Biomass in a Pyrolysis Process. Waste and Biomass Valorization, 3: 311-318.

Trenkel, M. E. (2010). Slow- and Controlled-Release and Stabilized Fertilizers: An Option for Enhancing Nutrient Use Efficiency in Agriculture. International Fertilizer Industry Association (IFA) Paris, France.

Trigo, C., Cox, L. and Spokas, K. (2016). Influence of pyrolysis temperature and hardwood species on resulting biochar properties and their effect on azimsulfuron sorption as compared to other sorbents. Science of the Total Environment, 566: 1454-1464.

Vaccari, F. P., Maienza, A., Miglietta, F., Baronti, S., Di Lonardo, S., Giagnoni, L., Lagomarsino, A., Pozzi, A., Pusceddu, E., Ranieri, R., Valboa, G. and Genesio, L. (2015). Biochar stimulates plant growth but not fruit yield of processing tomato in a fertile soil. Agriculture, Ecosystems and Environment, 207: 163-170.

Vaughn, S. F., Kenar, J. A., Thompson, A. R. and Peterson, S. C. (2013). Comparison of biochars derived from wood pellets and pelletized wheat straw as replacements for peat in potting substrates. Industrial Crops and Products, 51: 437-443.

Verardo, D. J., Froelich, P. N., McIntyre, A. (1990). Determination of organic carbon and nitrogen in marine sediments using the Carlo-Erba-NA-1500 Analyzer. Deep Sea Research, 37: 157–165.

Verheijen, F. G. A., Zhuravel, A., Silva, F. C., Amaro, A., Ben-Hur, M. and Keizer, J. J. (2019). The influence of biochar particle size and concentration on bulk density and maximum water holding capacity of sandy vs sandy loam soil in a column experiment. Geoderma, 347: 194-202.

Wang, Y., Li, M. and Yan H. (2021a). Ammonia volatilization from urea in alfalfa field with different nitrogen application rates, methods and timing. Agriculture, Ecosystems and Environment, 312: 107344.

Wang, H., Ren, T., Muller, K., Zwieten, L.V., Wang, H., Feng, H., Xu, C., Yun, F., Ji, X., Yin, Q., Shi, H. and Liu, G. (2021b). Soil type regulates carbon and nitrogen stoichiometry and mineralization following biochar or nitrogen addition. Science of The Total Environment, 753: 141645.

Wang, C., Lv, J., Coulter, J. A., Xie, J., Yu, J., Li, J., Zhang, J., Tang, C., Niu, T. and Gan, Y. (2020). Slow-Release Fertilizer Improves the Growth, Quality, and Nutrient Utilization ofWintering Chinese Chives (Allium tuberosum Rottler ex Spreng.). Agronomy, 10(381): 1-19.

Wang, H., Zhang, D., Zhang, Y., Zhai, L., Yin, B., Zhou, F., Geng, Y., Pan, J., Luo, J., Gu, B. and Liu H. (2018). Ammonia emissions from paddy fields are underestimated in China. Environmental Pollution, 235: 482-488.

Wang, Y., Yin, R. and Liu, R. (2014a). Characterization of biochar from fast pyrolysis and its effect on chemical properties of the tea garden soil. Journal of Analytical and Applied Pyrolysis, 110: 375-381.

Wang, J., Wang, D., Zhang, G., Wang, Y., Wang, C., Teng, Y. and Christie, P. (2014b). Nitrogen and phosphorus leaching losses from intensively managed paddy fields with straw retention. Agricultural Water Management, 141: 66-73.

Wang, Y., Lin, Y. X., Chiu, P. C., Imhoff, P. T. and Guo, M. X. (2015). Phosphorus release behaviors of poultry litter biochar as a soil amendment. Science of The Total Environment, 512-513: 454-463.

Wang, S., Zhao, X., Xing, G. and Yang, L. (2013). Large-scale biochar production from crop residue: A new idea and the biogas-energy pyrolysis system. BioResources 8(1): 8-11.

Weber, K. and Quicker, P. 2018. Properties of biochar. Fuel, 217: 240–261.

Wei, T., Yang, S., Cheng, S., Pei, M., Liu, H., Yu, Y. and Guo D. (2022). Transcriptome analysis reveals the responsive pathways to potassium (K^+) deficiency in the roots and shoots of grapevines. Scientia Horticulturae, 293: 110742.

Wei, S., Zhu, M., Fan, X., Song, J., Peng, P., Li, K., Jia, W. and Song, H. (2019). Influence of pyrolysis temperature and feedstock on carbon fractions of biochar produced from pyrolysis of rice straw, pine wood, pig manure and sewage sludge. Chemosphere, 218: 624-631.

Wen, P., Han, Y., Wu, Z., He, Y., Ye, B. C. and Wang, J. (2017). Rapid synthesis of a corncob-based semi-interpenetrating polymer network slow-release nitrogen. Arabian Journal of Chemistry, 10(7): 922-934.

Wendling, M., Buchi, L., Amosse, C., Sinaj, S., Walter, A. and Charles, R. (2016). Influence of root and leaf traits on the uptake of nutrients in cover crops. Plant and Soil, 409: 419-434.

Widowati, W and Asnah, A. (2014). Biochar Can Enhance Potassium Fertilization Efficiency and Economic Feasibility of Maize Cultivation. Journal of Agricultural Science, 6(2): 24-32.

Withers, P. J. A., Rodrigues, M., Soltangheisi, A., De Carvalho, T. S., Guilherme, L. R. G., Benites, V. D. M., Gatiboni, L. C., De Sousa, D. M. G., Nunes, R. D. S., Rosolem, C. A., Andreote, F. D., Oliveira, A. De, Coutinho, E. L. M. and Pavinato, P. S. (2018). Transitions to sustainable management of phosphorus in Brazilian agriculture. Scientific Reports, 8: 1–13.

Wu, Z., Wang, X., Liu, H., Zhang, H. and Miller, J. D. (2016). Some physicochemical aspects of water-soluble mineral flotation. Advances in Colloid and Interface Science, 235: 190-200.

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

Xu, R., Zhao, A., Yuan, J. and Jiang, J. (2012). pH buffering capacity of acid soils from tropical and subtropical regions of China as influenced by incorporation of crop straw biochars. Journal of Soils and Sediments, 12(4): 494–502.

Xue, B., Huang, H., Mao, M. and Liu, E. (2017). An investigation of the effect of ammonium sulfate addition on compound fertilizer granulation. Particuology, 31: 54–58.

Yan, L., Zhang, Z., Chen, Y., Gao, Q., Lu, W. and Abdelrahman, A. M. (2016). Effect of water and temperature on ammonia volatilization of maize straw returning. Effect of water and temperature on ammonia volatilization of maize straw returning. Toxicological & Environmental Chemistry, 98(5-6): 638-647.

Yang, H. I., Lou, K., Rajapaksha, A. U., Ok, Y. S., Anyia, A. O. and Chang, S. X. (2018). Adsorption of ammonium in aqueous solutions by pine sawdust and wheat straw biochars. Environmental Science and Pollution Research, 25(26): 25638-25647.

Yao, Y., Zeng, K. and Song, Y. (2020). Biological nitrification inhibitor for reducing N_2O and NH_3 emissions simultaneously under root zone fertilization in a Chinese rice field. Environmental Pollution, 114821.

Yao, Y., Gao, B., Zhang, M., Inyang, M. and Zimmerman, A. R. (2012). Effect of biochar amendment on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil. Chemosphere, 89: 1467–1471.

Ye, L., Camps-Arbestain, M., Shen, Q., Lehmann, J., Singh, B. and Sabir, M. (2019). Biochar effects on crop yields with and without fertilizer: a meta-analysis of field studies using separate controls. Soil Use Management, 36(1): 2-18.

Ye, R. and Horwath, W. R. (2017). Influence of rice straw on priming of soil C for dissolved organic C and CH_4 production. Plant and Soil, 417(1-2): 231-241.

Yi, S., Gao, B., Sun, Y., Wu, J., Shi, X., Wu, B. and Hu, X. (2016). Removal of levofloxacin from aqueous solution using rice-husk and wood-chip biochars. Chemosphere, 150: 694–701.

Yuan, H., Lu, T., Wang, Y., Chen, Y. and Lei, T. (2016a). Sewage sludge biochar: Nutrient composition and its effect on the leaching of soil nutrients. Geoderma, 267: 17-23.

Yuan, Z, Ata-Ul-Karim, S. T., Cao, Q., Lu, Z,, Cao, W., Zhu, Y. and Liu, X. (2016b). Indicators for diagnosing nitrogen status of rice based on chlorophyll meter readings. Field Crops Research, 185: 12-20.

Yu, H., Zou, W., Chen, J., Chen, H., Yu, Z., Huang, J., Tang, H., Wei, X. and Gao, B. (2019). Biochar amendment improves crop production in problem soils: A review. Journal of Environmental Management, 232: 8-21.

Yu, Q., Ye, J., Yang, S., Fu, J., Ma, J., Sun, W., Jiang L., Wang, Q and Wang, J. (2013). Effects of Nitrogen Application Level on Rice Nutrient Uptake and Ammonia Volatilization. Rice Science, 20(2): 139–147.

Zeb, N. (2015). Effect of Potassium and Maleic Hydrazide on Growth and Flower Quality of Chrysanthemum (Dendranthema grandiflorum). Sarhad Journal of Agriculture, 31(4): 210-216.

Zhang, X., Zhang, P., Yuan, X., Li, Y. and Han, L. (2020). Effect of pyrolysis temperature and correlation analysis on the yield and physicochemical properties of crop residue biochar. Bioresource Technology, 296: 122318.

Zhang, Z., Zhu, Z., Shen, B. and Liu, L. (2019a). Insights into biochar and hydrochar production and applications: A review. Energy, 171: 581-598.

Zhang, Q., Song, Y., Wu, Z. Yan, X., Gunina, A., Kuzyakov, Y. and Xiong, Z. (2019b). Effects of six-year biochar amendment on soil aggregation, crop growth, and nitrogen and phosphorus use efficiencies in a rice-wheat rotation. Journal of Cleaner Production, 242: 118435.

Zhang, J., Liu, J. and Liu, R. (2015). Effects of pyrolysis temperature and heating time on biochar obtained from the pyrolysis of straw and lignosulfonate. Bioresource Technology, 176: 288–291.

Zhao, W., Zhou, Q., Tian, Z., Cui, Y., Liang, Y. and Wang, H. (2020). Apply biochar to ameliorate soda saline-alkali land, improve soil function and increase corn nutrient availability in the Songnen Plain. Science of the Total Environment, 722: 137428.

Zhao, B., O'Connor, D., Zhang, J., Peng, T., Shen, Z., Tsang, D. C. W. and Hou, D. (2018). Effect of pyrolysis temperature, heating rate, and residence time on rapeseed stem derived biochar. Journal of Cleaner Production, 174: 977-987.

Zhao, S. X., Ta, N. and Wang, X. D. (2017). Effect of Temperature on the Structural and Physicochemical Properties of Biochar with Apple Tree Branches as Feedstock Material. Energies, 10(1293): 1-15.

Zhao, L., Cao, X. D., Masek, O. and Zimmerman, A. (2013). Heterogeneity of biochar properties as a function of feedstock sources and production temperatures. Journal of Hazardous Materials, 256: 1-9.

Zheng, J., Han, J., Liu, Z., Xia, W., Zhang, X., Li, L., Liu, X., Bian, R., Cheng, K., Zheng, J. and Pan, G. (2017). Biochar compound fertilizer increases nitrogen productivity and economic benefits but decreases carbon emission of maize production. Agriculture, Ecosystems and Environment, 241: 70-78.

Zhou, G., Xu, X., Qiu, X. and Zhang, J. (2019). Biochar influences the succession of microbial communities and the metabolic functions during rice straw composting with pig manure. Bioresource Technology, 272: 10-18.

Zhou, G. W., Zhang, W., Ma, L. J., Guo, H. J., Min, W., Li, Q., Liao, N. and Hou, Z. N. (2016). Effects of saline water irrigation and N application rate on NH_3 volatilization and N use efficiency in a drip-irrigated cotton field. Water Air Soil Pollution, 227: 1-17.

Zhu, H., Yang, J. S., Yao, R. J., Wang, X. P., Xie, W. P., Zhu, W., Liu, X. Y., Cao, Y. F. and Tao, J. Y. (2020). Interactive effects of soil amendments (biochar and gypsum) and salinity on ammonia volatilization in coastal saline soil. Catena, 190: 104527.

Zhu, Q., Peng, X. and Huang, T. (2015). Contrasted effects of biochar on maize growth and n use efficiency depending on soil conditions. International Agrophysics, 29: 257-266.

Ziadi, N., Whalen, J. K., Messiga, A. J. and Morel, C. (2013). Assessment and Modeling of Soil Available Phosphorus in Sustainable Cropping Systems. Advances in Agronomy, 122: 85-126.

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