International Journal of Horticultural Science 2025, 31: 88-94.
https://doi.org/10.31421/ijhs/31/2025/15171

Effect of different biochar on acidic soil, growth, and nutritional status of oil palm (*Elaeis guineensis* Jacq.) under the nursery condition

Aleiadeh, H.

Faculty of Plantation and Agrotechnology, Universiti Tecknologi MARA (UiTM),
Sarawak Branch, Samarahan Campus, 94300 Kota Samarahan, Sarawak
Author for correspondence: hemamaleiadeh@gmail.com

Summary: Biochar is a widely known organic amendment that enhances plant growth and productivity through improving soil condition and fertility. However, plant and soil response differently to various types of biochar. Therefore, the major objective of the present study was to determine the effect of two types of biochar; vetiver grass biochar (VGB) and pineapple leaf biochar (PLB) on selected soil properties and understand their role in improving plant growth and nutritional status. Net house experimental study with oil palm (*Elaeis guineensis* Jacq.) seedlings was conducted at the farm unit of UiTM Samarahan campus for 240 days between November 2022 and July 2023 in order to understand the impact of different application rates (25, 50, 75, and 100%) of vetiver grass biochar and pineapple leaf biochar on selected soil properties including pH, electrical conductivity (EC), nitrogen, phosphorus, and potassium content, plant growth parameters including plant height, bole diameter, leaf number, SPAD chlorophyll content, plant dry weight, and plant's NPK content. The experimental design used is randomized complete block design (RCBD) with 8 treatments, 3 replicates, and each replicate has 6 plants. The analysis of variance (ANOVA) and DMRT were used to analyze the collected data from soil and plant parameters. The analysis process was accomplished using SAS package ($P<0.05$): version 9.4 (SAS, 2013). Based on the results, vetiver grass biochar and pineapple leaf biochar enhanced soil pH, EC, and NPK content. They also improved the growth and nutritional status of oil palm seedlings. Soil enhancement was the best with 100% pineapple leaf biochar. In addition, the highest mean value of plant height, bole diameter, leaf number, SPAD chlorophyll content, plant dry weight, and plant's NPK content was observed in plants treated with 100% pineapple leaf biochar. Therefore, vetiver grass biochar and pineapple leaf biochar have the potential to enhance acidic and poor-fertile soil, and improve oil palm seedlings growth and nutritional status.

Aleiadeh, H. (2025): Effect of different biochar on acidic soil, growth, and nutritional status of oil palm (*Elaeis guineensis* Jacq.) under the nursery condition. International Journal of Horticultural Science 31: 88-94. https://doi.org/10.31421/ijhs/31/2025/15171

Key words: vetiver grass, pineapple leaf, biochar, oil palm

Introduction

Biochar is a stable charcoal product that is usually produced in a controlled environment by heating biomass through slow pyrolysis process with limited oxygen at high temperature (Aziz et al., 2023). Biochar is an eco-friendly product and well-known organic amendment for problematic soils (Torabian et al., 2021). Biochar application is a promising strategy that can be used to boost plant growth and increase the production yield through improving soil quality (Calcan et al., 2022). Numerous studies indicate the improvement of soil properties using biochar including soil pH, EC, and NPK content (Albalasmeh et al., 2023). However, soil response differently to various types of biochar (Smider & Singh, 2014). The increase in soil pH with the biochar addition was previously reported (Martinsen et al., 2015; Bindu et al., 2016; Albalasmeh et al., 2023). The decrease in soil pH with the biochar addition was previously reported (Ippolito et al., 2016; Zhang et al., 2019; Liu et al., 2020). The increase in soil EC as a result of the biochar addition was previously observed (Mia et al., 2014; Pandian et al., 2016; Joseph et al., 2021). On the other hand, a reduction of soil EC with the biochar addition was reported (Thomas et al., 2013; Premalatha et al., 2023). The increase in soil N content as a response to the biochar addition was previously observed (Jeffery et al., 2011; Jones et al., 2012; Abbruzzini et al., 2019). Contradictory, the reduction of soil N content with the biochar addition was reported (Singh et al., 2010; Cayuela et al., 2013; Harter et al., 2014). The increase in soil P upon the addition of biochar was preciously noticed (DeLuca et al., 2015; Xu et al., 2018; Aleiadeh et al., 2024). On the other hand, a reduction soil P content with the biochar addition was previously observed (Schneider & Haderlein, 2016; Trazzi et al., 2016; Ngatia et al., 2017). The increase in soil K content with the addition of biochar was previously stated (Bindu et al., 2020; Aleiadeh et al., 2024) while Alazzaz et al. (2020) reported that the addition of biochar reduced the P content in soil. Biochar can also stimulate the plant growth and enhance its production yield and nutritional status through improving soil quality (Premalatha et al., 2023). Several studies indicated that biochar application enhances plant growth and yield (Rondon et al., 2004; Lehmann et al., 2006; Haefele et al., 2011; Lee et al., 2013; Akhtar et al., 2015; Kim et al., 2016; Adekiya et al., 2020; Jiang et al., 2020). However, several studies indicated that the addition of biochar had no effect on plant growth and yield (Chan et al., 2007; Nzanza et al., 2012; Deng et al., 2017). Furthermore, other studied indicated a reduction in plant growth and yield with the biochar addition (Asai et al., 2009; Gaskin et al., 2010). The enhancement of plant nutrient content with the biochar addition was previously observed and reported (Major et al., 2010; Olmo et al., 2014; Mohawesh et al., 2021; Calcan et al., 2022). The role of biochar in soil and plant is highly influenced by the type of feedstock used (Albalasmeh et al., 2023). Therefore, the main objective of this study was to determine the effect of different application rates of biochar produced from different feedstocks (vetiver grass and pineapple leaf) on certain soil properties, growth parameters, and nutrients content of oil palm under the nursery condition.

Materials and methods

Biochar production

The fresh Biochar was obtained from the slow pyrolysis process of vetiver grass and pineapple leaves at 350 °C using a large chamber muffle furnace (Type 62700; Thermo Scientific Barnstead/Thermolyne, USA) (Bohari et al., 2020) in the Natural Products and Research Development Center Laboratory (NPRDC), Faculty of Plantation and Agrotechnology, UiTM Samarahan Campus. Then the biochar samples were cooled down, collected, washed with water to improve any impurities (Siti et al., 2021).

Biochar characterization

The physicochemical properties of pineapple leaf biochar were obtained from Bohari et al., (2020). Vetiver grass biochar (VGB) was converted into powder form and passed through 0.2 mm sieve for characterization purpose (Shetty & Prakash 2020). The pH value of the biochar was recorded using portable pH meter (Make-EUTECH pH Tester) following the same method used by Sahoo et al. (2021). The EC value was measured using EC meter (Mettler-Toledo AG 8603 Schwerzenbach, Switzerland) following the same steps used by Bohari et al. (2020). Total N was determined using CNS Analyzer following the dry combustion method (Shetty & Prakash 2020). Phosphorus and potassium content of the biochar were determined according to the standard procedures of the United States Salinity Laboratory Staff (United States Salinity Laboratory Staff, 1954). The physicochemical properties of pineapple leaf biochar and vetiver grass biochar are presented in ***Table 1*** and ***Table 3***, respectively.

Soil sampling and analysis pre-planting stage

Soil samples were collected using a shovel from a depth of 0-20 cm in the farm field located at the Universiti Teknologi MARA Samarahan Campus. The soil is classified as mineral soil. Soil samples were air-dried, and passed through 2 mm sieve for analysis purpose. Soil pH was measured using a portable pH meter (1:2.5) (Jackson, 1973). Soil EC was measured using EC meter at soil: water suspension ratio of 1.1 (Albalasmeh et al., 2023). Soil nitrogen content was determined using the Kjeldahl method (AOAC, 1995). Phosphorus content and exchangeable potassium in soil were measured using Olsen method and atomic absorption respectively (Albalasmeh et al., 2023). The initial soil properties are presented in ***Table 4.***

Table 1. Physicochemical properties of pineapple leaf biochar.

Parameter	Unit	Value
pH	–	8.78
EC	mS cm^{-1}	7.38
N	%	8.33
P	%	0.39
K	%	48.32

Source: Bohari et al. (2020)

Table 2. Composition of treatments, rate and quantity of biochar.

Treatment	VGB (g/plant)	PLB (g/plant)
B_{25}	35	24.5
B_{50}	70	49
B_{75}	105	73.5
B_{100}	140	98

Note: VGB = vetiver grass biochar, PLB = pineapple leaf biochar. Different letters B_{25}, B_{50}, B_{75}, B_{100} = biochar application at 25, 50, 75, and 100% rate.

Table 3. Physicochemical properties of vetiver grass biochar.

Parameter	Unit	Value
pH	–	8.41
EC	mScm^{-1}	5.48
N	%	2.93
P	%	0.35
K	%	7.25

Note: pH = alkalinity, EC= electrical conductivity, N, P, and K = nitrogen, phosphorus, and potassium content.

Table 4. Initial reading of soil parameters.

Parameter	Unit	Value
pH	–	4.3
EC	mScm^{-1}	2.2
N	%	0.13
P	ppm	265
K	ppm	91.6

Note: pH = alkalinity, EC= electrical conductivity, N, P, and K = nitrogen, phosphorus, and potassium content.

Net house experiment with oil palm

A net house experiment was conducted at the Farm Unit, UiTM Samarahan Campus with the coordination of (1°26'45.7"N 110°27'08.2" E), Kota Samarahan, Sarawak, Malaysia, for 240 days between November 2022 and July 2023. The experimental technique used is cultivation of oil palm seedlings in polybag filled with soil. The dimensions of the polybag used are 26 cm depth × 30 cm width. Each polybag was filled with 3 kg of soil and one seedling. The soil was mixed with two types of biochar viz., VGB and PLB at 25, 50, 75, and 100% application rates prior the transplanting stage. Then, the oil palm seedlings, variety *Elaeis guineensis* Jacq. were immediately transplanted into the polybags. After completing the transplanting process, the biochar treatments were applied once every two months. The polybag experiment consists of eight treatments and three replicates, each replicate consists of six plants, making a total of 144 experimental units arranged in a randomized complete block design (RCBD). The seedlings were watered three times daily using automatic drip irrigation system. Biometric parameters such as plant height (cm), bole diameter (cm), leaf number, chlorophyll content (SPAD unit), and plant dry weight (g) were observed and recorded at the end of the experiment. The quantities of biochar applied were prepared based on the amount of nutrients provided to oil palm seedlings according to Rankine & Fairhurst (1999). The rate and quantity of VGB and PLB used are shown in ***Table 2***.

Plant and soil analysis after harvesting

After eight months, the plants were harvested and destructively sampled from each treatment, washed with tap water, and oven dried at 65 °C for 72 hr. After completing the drying process, the weight of plants was obtained using (A&D GF-300 Precision Balance) and recorded as plant dry weight (Zubir et al., 2020). For nutrient analysis, plants were prepared following the same steps in (Gupta, 2007). Total N and P in plants were obtained using auto-analyzer (QuikChem, Series 8000, Lachat Instruments Inc., USA), while total K was measured using atomic absorption spectrophotometer (Perkin-Elmer 5100 PC) (Mohidin et al., 2015). Soil samples were also extracted and collected from each treatment, air-dried, and sieved (2 mm) for analysis purpose. Soil pH, EC, nitrogen content, phosphorus content, and exchangeable potassium were measured using the same methods mentioned previously.

Statistical analysis

All data collected from the measured soil and plant parameters were analyzed using ANOVA with the Statistical Analysis System version 9.4 (SAS, 2013). Data were also subjected to Duncan's Multiple Range Test (DMRT) in order to detect the significant groupings at P<0.05 significance level.

Results and discussion

Vetiver grass biochar characteristics

The main characteristics of biochar from vetiver grass are summarized in ***Table 3***. The vetiver grass biochar is characterized by high pH, EC, N, P, and K content (***Table 3***).

Initial soil properties

The analysis of the net house experiment soil shows that soil has pH 4.3, EC 2.2 $mScm^{-1}$, N 0.13%, P 265 ppm, and K 91.6 ppm (***Table 4***).

Effect of biochar on soil properties

The effect of biochar application on soil pH is shown in ***Table 5***. The application of VGB and PLB significantly enhanced soil pH. Between the VGB treatments, soil pH reached a maximum value of 7.63 at the B_{100} application rate. Between the PLB treatments, soil pH reached a maximum value of 7.88 at B_{100} application rate. The maximum value of soil pH at B_{100} application rate of VGB and PLB were not significantly different. The increase in soil pH after the application of VGB and PLB can be explained by the high alkalinity nature of the VGB (8.41) (***Table 3***) and PLB (8.78) (***Table 1***). Curaqueo et al. (2014) showed that soil pH value increased with the biochar addition. Albalasmeh et al., (2023) reported that soil pH increased with the biochar application compared with the control treatment. Similarly, Aleiadeh et al. (2024) reported that the application of biochar significantly increased soil pH. The increase in soil pH with the biochar application could be related to the alkalinity nature of the biochar which mainly depends on the type of feedstock used to produce the biochar (Glaser et al., 2002). This increase could also be related to the addition of base cations and nutrients to soil and to the occupation of soil exchange sites by the exchangeable bases when the biochar is applied (Xiao et al., 2016). The effect of biochar application on soil EC is shown in Table 5. The application of VGB and PLB significantly increased soil EC. This increase was more noticed at B_{100} application rate, where the EC reached the maximum value of 4.41 under VGB and 5.86 under PLB (***Table 5***). The increase in soil EC with the biochar application is due to the high EC vale of VGB (***Table 3***) and PLB (***Table 1***). Nigussie et al., (2012) studied the effect of biochar application on soil. They found that soil EC significantly increased with the biochar application. Also, Albalasmeh et al. (2023) found that the biochar application significantly increased soil EC value. The results showed significant responses of nitrogen (N), phosphorus (P), and potassium (K) content to the application of biochar. Under the VGB treatments, the highest N content was seen in soil treated with B_{100} application rate. Similar thing was noticed under the PLB treatments. However, at B_{100} application rate, N, P, and K content of soil was slightly higher in PLB compared to VGB (***Table 5***). This increase with the application is due to the ability of biochar to enhance the nutritional status of soil and enrich it with more nutrients (Xiao et al., 2016). The application of biochar enhanced the soil nutritional status by increasing soil total nitrogen, and available phosphorus and potassium contents (Olmo et al., 2014; Vaccari et al., 2015).

Effect of biochar on plant growth

The effect of biochar application on plant growth performance is shown in ***Table 6***. Plant height was significantly affected by biochar application (***Table 6***). The application of VGB and PLB significantly increased the plant height. Between the VGB treatments, plant height reached a maximum value of 50.53 cm at the B_{100} application rate. Between the PLB treatments, plant height reached a maximum value of 62.22 cm at B_{100} application rate. Sokchea & Preston (2011) reported that plant height was enhanced with the biochar application. Bijay-Singh & Craswell (2021) found that biochar application increased the height of ginger plant. Albalasmeh et al. (2023) also reported that biochar application increased the height of wheat and barley. Ajeng et al. (2020) found that biochar application increased the plant height of oil palm. Aleiadeh (2024) confirmed that biochar application enhanced the growth of oil palm in terms of height. Bole diameter and leaf number were highly influenced by the addition of biochar (***Table 6***). Between all the treatments, the maximum value of bole diameter (4.86 cm) and leaf number (19.33) were detected in plants treated with B_{100} application rate of PLB. The biochar application increased the plant' bole diameter and leaf number (Aleiadeh et al., 2024). The increase

Table 5. Effect of biochar on selected soil properties.

Treatment	pH	EC ($mScm^{-1}$)	N (%)	P (ppm)	K (ppm)
VGB					
B_{25}	5.76^d	2.98^d	0.19^d	271^d	105.6^d
B_{50}	6.35^c	3.33^c	0.31^c	2.84^c	122.4^c
B_{75}	7.39^b	3.86^b	0.44^b	296^b	138.2^b
B_{100}	7.63^a	4.41^a	0.56^a	312^a	159.0^a
PLB					
B_{25}	6.11^d	3.66^d	0.89^d	276^d	117.3^d
B_{50}	6.72^c	4.11^c	1.33^c	288^c	139.4^c
B_{75}	7.54^b	4.55^b	2.17^b	303^b	162.0^b
B_{100}	7.88^a	5.86^a	2.49^a	317^a	184.7^a

Note: Different letters in the same column indicate significant ranking orders by DMRT at $p<0.05$. B_{25}, B_{50}, B_{75}, B_{100} = biochar application at 25, 50, 75, and 100% rate.

Table 6. Effect of biochar on plant growth parameters.

Treatment	Chlorophyll content (SPAD unit)	Plant height (cm)	Bole diameter (cm)	Leaf number	Dry weight (g)
VGB					
B_{25}	25.75^d	33.22^d	2.08^d	5.33^d	104.95^d
B_{50}	34.18^c	39.16^b	2.57^c	9.18^c	126.19^c
B_{75}	41.63^b	46.31^c	2.94^b	11.82^b	134.33^b
B_{100}	47.55^a	50.53^a	3.19^a	14.24^a	148.61^a
PLB					
B_{25}	33.84^d	39.72^d	3.51^c	9.83^d	121.66^d
B_{50}	38.20^c	46.38^c	3.93^b	12.34^c	139.11^c
B_{75}	46.92^b	54.82^b	4.78^{ab}	15.71^b	158.79^b
B_{100}	53.82^a	65.22^a	4.86^a	19.33^a	171.22^a

Note: Different letters in the same column indicate significant ranking orders by DMRT at $p<0.05$. B_{25}, B_{50}, B_{75}, B_{100} = biochar application at 25, 50, 75, and 100% rate.

in plant's bole diameter and leaf number can be related to increased soil N and K content because of the biochar application (***Table 5***). Plant's bole diameter and leaf number are mainly affected and enhanced by the addition of N and P source (Astuti et al., 2015; Adileksana et al., 2020). The results showed that biochar application enhanced the plant's chlorophyll content (***Table 6***). The highest chlorophyll content with the highest application rate (B_{100}) of PLB. Hua et al. (2012) stated that biochar application increased the chlorophyll contents of ryegrass. Albalasmeh et al. (2023) reported that biochar application increased the chlorophyll contents in wheat and barley. The increase in plant's chlorophyll content can be related to increased soil nitrogen content due to the biochar application (***Table 5***). Plant dry weight was influenced by biochar application (***Table 6***). The maximum value of plant's dry weight was noticed under the highest application rate (B_{100}) of PLB. Lee et al. (2013) reported that biochar application significantly increased the dry weight of soybean. Jabborova et al. (2021) also reported that biochar application increased the plant's dry weight. González et al. (2022) showed that plant's dry weight was enhanced with the biochar application. According to Albalasmeh et al. (2023) plant's weight including dry weight is usually influenced by the soil conditions and nutrient content, which are mainly enhanced by the addition of biochar.

Table 7. Effect of biochar on plant's NPK content.

Treatment	N (%)	P (ppm)	K (ppm)
VGB			
B_{25}	1.83^d	2.7^d	34.8^d
B_{50}	2.26^c	3.1^c	42.3^c
B_{75}	2.61^b	3.4^b	48.5^b
B_{100}	2.87^a	3.8^a	54.9^a
PLB			
B_{25}	2.07^d	2.8^d	45.2^d
B_{50}	2.35^c	3.3^c	59.1^c
B_{75}	2.76^b	3.4^b	68.5^b
B_{100}	3.12^a	3.9^a	77.9^a

Note: Different letters in the same column indicate significant ranking orders by DMRT at $p<0.05$. B_{25}, B_{50}, B_{75}, B_{100} = biochar application at 25, 50, 75, and 100% rate.

Effect of biochar on plant's nutrient content

The effect of biochar application on plant's nutrient content is shown in ***Table 7***. Plant's NPK content was significantly influenced by biochar application. Between all treatments, Plant's NPK content reached the highest value at B_{100} application rate of PLB (***Table 7***). Salim (2016) reported that NPK content in wheat was increased with the biochar application. Albalasmeh et al. (2023) found that biochar application slightly increased N and P content in wheat and barley. He also found that K content in both plants was increased with biochar application. Biederman & Stanley Harpole (2013) showed that soil and plant nutrient contents were increased as a result of biochar addition. The increase in plant's NPK content can be attributed to the NPK content of VGB (***Table 3***) and PLB (***Table 1***), which increased the nutrient content in soil and plant (***Table 5*** and ***Table 7***).

Conclusions

Vetiver grass biochar and pineapple leaf biochar have the potential to be used as soil amendments. Vetiver grass biochar and pineapple leaf biochar enhanced soil pH, EC, nitrogen content, phosphorus content, and potassium content. In addition, they also improved the growth and nutritional status of oil palm (*Elaeis guineensis* Jacq.) seedlings. Based on the findings, 100% application rate of pineapple leaf biochar had the best effect on oil palm seedlings cultivated in acidic-poor fertile soil.

Acknowledgements

The author is grateful to the Universiti Teknologi MARA Cawangan Sarawak, Samarahan Campus for the technical support provided during the experimental study.

References

Adekiya, A. O., Agbede, T. M., Olayanju, A., Ejue, W. S., Adekanye, T. A., Adenusi, T. T., Ayeni, J. F. (2020): Effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam alfisol. Scientific World Journal. 2020, 1–9. https://doi.org/10.1155/2020/9391630.

Adileksana, C., Yudono, P., Purwanto, B. H., Wijoyo, R. B. (2020): The growth performance of oil palm seedlings in pre-nursery and main nursery stages as a response to the substitution of NPK compound fertilizer and organic fertilizer. Caraka Tani: Journal of Sustainable Agriculture. 35(1): 89–97. https://doi.org/10.20961/carakatani.v35i1.33884.

Ajeng, A. A., Abdullah, R., Malek, M. A., Chew, K. W., Ho, Y. C., Ling, T. C., Lau, B. F., Show, P. L. (2020): The effects of biofertilizers on growth, soil fertility, and nutrients uptake of oil palm (*Elaeis guineensis*) under greenhouse conditions. Processes. 8(12): 1–16. https://doi.org/10.3390/pr8121681.

Akhtar, S., Andersen, M. N., Liu, F. (2015): Biochar mitigates salinity stress in potato. Journal of Agronomy and Crop Science. 201: 368–378. https://doi.org/10.1111/jac.12132.

Alazzaz, A., Usman, A. R. A., Ahmad, M., Ibrahim, H. M., Elfaki, J., Sallam, A. S., Mutair, A. A., Al-Wabel, M. (2020): Potential short-term negative versus positive effects of olive mill-derived biochar on nutrient availability in a calcareous loamy sand soil. PLOS one 15, e0232811. https://doi.org/10.1371/journal.pone.0232811.

Albalasmeh, A., Mohawesh, O., Alqudah, A. (2023): The potential of biochar application to enhance soil quality, yield, and growth of wheat and barley under rainfed conditions. Water Air Soil Pollution 234, 463. https://doi.org/10.1007/s11270-023-06493-4.

Aleiadeh, H. (2024): Optimization of fertilizer use efficiency, soil quality and oil palm (*Elaeis guineensis* Jacq.) growth with biochar under drip irrigation conditions. International Journal of Horticultural Science 30: 31-36. https://doi.org/10.31421/ijhs/30/2024/14191.

Aleiadeh, H., Idris, J., Mohidin, H., Omar, L., Man, S., Munir, S., Jong, V. (2024): Effect of co-application of vetiver grass biochar and NPK fertilizer on the growth of oil palm (*Elaeis guineensis* Jacq.) seedlings and soil chemical properties. Malaysian Journal of Soil Science. 28. 26–37.

AOAC, A. (1995): Official methods of analysis (16th ed.). Washington DC, USA: Association of official analytical chemists.

Aziz, S., Bibi, S., Hasan, M. M., Biswas, P., Ali, M. I., Bilal, M., Chopra, H., Mukerjee, N., Maitra, S. (2023): A review on influence of biochar amendment on soil processes and environmental remediation. Biotechnology and Genetic Engineering Reviews. 1-35. https://doi.org/10.1080/02648725.2022.2122288.

Biederman, L. A., Stanley Harpole, W. (2013): Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. Global Change Biology Bioenergy. 5(2): 202-214. https://doi.org/10.1111/gcbb.12037.

Bijay-Singh, Craswell, E. (2021): Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. Discover Applied Sciences. 3(4): 1–24. https://doi.org/10.1007/s42452-021-04521-8.

Bohari, N., Mohidin, H., Idris, J., Andou, Y., Man, S., Saidan, H., Mahdian, S. (2020): Nutritional characteristics of biochar from pineapple leaf residue and sago waste. Pertanika Journal of Science and Technology. 28 (Special issue 2), 273–286. https://doi.org/10.47836/pjst.28.S2.21.

Calcan, S. I., Pârvulescu, O. C., Ion, V. A., Răducanu, C. E., Bădulescu, L., Madjar, R., Dobre, T., Egri, D., Moț, A., Iliescu, L. M., Jerca, I. O. (2022): Effects of biochar on soil properties and tomato growth. Agronomy. 12(8): 25–27. https://doi.org/10.3390/agronomy12081824.

Cayuela, M. L., Sanchez-Monedero, M. A., Roig, A., Hanley, K., Enders, A., Lehmann, J. (2013): Biochar and denitrification in soils: When, how much and why does biochar reduce N_2O emissions? Scientific Reports. 3. 1732. https://doi.org/10.1038/srep01732.

Chan, K. Y., Meszaros, I., Downie, A., Joseph, S. (2007): Agronomic values of greenwaste biochar as a soil amendment. Australian journal of Soil Research. 45: 629–634. https://doi.org/10.1071/ SR07109.

Curaqueo, G., Meier, S., Khan, N., Cea, M., Navia, R. (2014): Use of biochar on two volcanic soils: Effects on soil properties and barley yield. Journal of Soil Science and Plant Nutrition. 14(4): 911–924. https://doi.org/10. 4067/s0718-95162014005000072.

De Luca, T. H., MacKenzie, M. D., Gundale, M. J. (2015): "Biochar effects on soil nutrient transformation," in biochar for environment management: Science and Technology. Editors J. Lehmann and S. Joseph (London: Earthscan), 419–425.

Glaser, B., Lehmann, J., Zech, W. (2002): Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A review. Biology and Fertility of Soils. 35(4): 219–230. https://doi.org/10.1007/ s00374-002-0466-4.

Gupta, P. K. (2007): Soil, plant, water and fertilizer analysis (second edition). India: Agrobios.

Hua, L., Chen, Y., Wu, W. (2012): Impacts upon soil quality and plant growth of bamboo charcoal addition to Vol:. (1234567890) composted sludge. Environmental Technology. 33(1): 61–68. https://doi.org/10.1080/09593330.2010.549845.

Ippoloito, J. A., Ducey, T. F., Cantrell, K.B., Novak, J. M., Lentz, R. D. (2016): Designer acidic biochar influences calcareous soil characteristics. Chemosphere 142. 184–191. https://doi.org/10.1016/j.chemosphere.2015.05.092.

Jabborova, D., Wirth, S., Halwani, M., Ibrahim, M. F. M., El Azab, I. H., El-Mogy, M. M. Elkelish, A. (2021): Growth response of ginger (*Zingiber officinale*), its physiological properties and soil enzyme activities after biochar application under greenhouse conditions. Horticulture. 7(8): 1–12. https://doi.org/10.3390/horticulturae7080250.

Jackson, M. L. (1973): Soil chemical analysis (Prentice Hall of India Pvt. Ltd., New Jersey.

Jeffery, S., Verheijen, F. G. A., van der Velde, M., Bastos, A. C. (2011): A quantitative review of the effects of biochar application to soils on crop productivity using meta-anal ysis. Agriculture, Ecosystems and Environment. 144(1): 175–187. https://doi.org/10.1016/j.agee.2011.08.015.

Jiang, S., Liu, J., Wu, J., Dai, G., Wei, D., Shu, Y. (2020): Assessing biochar application to immobilize Cd and Pb in a contaminated soil: A field experiment under a cucumber-sweet potato-rape rotation. Environmental Geochemistry and Health. 42: 4233–4244. https://doi.org/10.1007/s10653-020-00564-9.

Jones, D. L., Rousk, J., Edwards-Jones, G., DeLuca, T. H., Murphy, D. V. (2012): Biochar-mediated changes in soil quality and plant growth in a three year field trial. Soil Biology and Biochemistry. 45. 113–124. https://doi.org/10.1016/j.soilbio.2011.10.012.

Joseph, S., Cowie, A. L., Zwieten, L. V., Bolan, N., Budai, A., Buss, W. Cayuela, M., L., Graber, E. R., Ippolito, J. A., Kuzyakov, Y., Luo, Y., Ok, Y. K., Palansooriya, K. N., Shepherd, J., Stephens, S., Weng, Z., H., Lehmann, J. (2021): How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. Global Change Biology Bioenergy. 13: 1731–1764. https://doi.org/10.1111/gcbb.12885.

Kim, H-S., Kim, K-R., Yang, J. E., Ok, Y. S., Owens, G., Nehls, T., Wessolek, G. Kim, K. H. (2016): Effect of biochar on reclaimed tidal land soil properties and maize (*Zea mays* L.) response. Chemosphere 142: 153–159. https://doi.org/10.1016/j.chemosphere.2015.06.041.

Lee, S., Shah, H. S., Igalavitkana, A. D., Awad, Y. M., Ok, Y. (2013): Enhancement of C3 and C4 plants productivity in soils amended with biochar and polyacrylamide. Tech. Bull. Food and Fertilizer Technology Center. Global Asia (East Pacific). 12.

Lehmann, J., Gaunt, J., Rondon, M. (2006): Biochar sequestration in terrestrial ecosystems: A review. Mitigation and Adaptation Strategies for Global Change. 11: 403–427. https://doi.org/10.1007/ s11027-005-9006-5.

Major, J., Rondon, M., Molina, D., Riha, S. J., Lehmann, J. (2010): Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant and Soil. 333: 117–128. https://doi.org/10.1007/s11104-010-0327-0.

Martinsen, V., Alling, V., Nurida, N. L., Mulder, J., Hale, S. E., Ritz, C., Rutherford, D. W., Heikens, A., Breedveld, G. D., Cornelissen, G. (2015): pH effects of the addition of three biochars to acidic Indonesian mineral soils. Soil Science and Plant Nutrition. 61(5): 821. https://doi.org/10.1080/00380768.2015.1052985.

Mia, S., van Groenigen, J. W., van de Voorde, T. F. J., Oram, N. J., Bezemer, T. M., Mommer, L., Jeffery, S. (2014): Biochar application rate affects biological nitrogen fixation in red clover conditional on potassium availability. Agriculture, Ecosystems and Environment. 191: 83–91. https://doi.org/10.1016/j.agee.2014.03.011.

Mohawesh, O., Albalasmeh, A., Gharaibeh, M., Deb, S., Simpson, C., Singh, S., Al-Soub, B., Hanandeh, A. E. (2021): Potential use of biochar as an amendment to improve soil fertility and tomato and bell pepper growth performance under arid conditions. Journal of Soil Science and Plant Nutrition. 21: 2946–2956. https://doi.org/10.1007/s42729-021-00580-3.

Mohidin, H., Hanafi, M. M., Rafii, Y. M., Abdullah, S. N. A., Idris, A. S., Man, S., Idris, J., Sahebi, M. (2015): Determination of optimum levels of nitrogen, phosphorus and potassium of oil palm seedlings in solution culture. Bragantia. 74(3): 247–254. https://doi.org/10.1590/1678-4499.0408.

Ngatia, L. W., Hsieh, Y. P., Nemours, D., Fu, R., Taylor, R. W. (2017): Potential phosphorus eutrophication mitigation strategy: Biochar carbon composition, thermal stability and pH influence phosphorus sorption. Chemosphere. 180: 201–211. https://doi.org/10.1016/j.chemosphere.2017.04.012.

Nigussie, A., Kissi, E., Misganaw, M., Ambaw, G. (2012): Effect of biochar application on soil properties and nutrient uptake of lettuces (*Lactuca sativ*a) grown in chromium polluted soils. American-Eurasian Journal of Agricultural & Environmental Sciences. 12(3): 369376.

Nzanza, B., Marais, D., Soundy, P. (2012): Effect of arbuscular mycorrhizal fungal inoculation and biochar amendment on growth and yield of tomato. International Journal of Agriculture and Biology. 14: 965–969.

Olmo, M., Alburquerque, J. A., Barrón, V., del Campillo, M. C., Gallardo, A., Fuentes, M., Villar, R. (2014): Wheat growth and yield responses to biochar addition under Mediterranean climate conditions. Biology and Fertility of Soils. 50(8): 1177–1187. https://doi.org/10.1007/s00374-014-0959-y.

Pandian, K., Subramaniayan, P., Gnasekaran, P., Chitraputhirapillai, S. (2016): Effect of biochar amendment on soil physical, chemical and biological properties and groundnut yield in rainfed alfisol of semi-arid tropics. Archives of Agronomy and Soil Science. 62: 1293–1310. https://doi.org/10.1080/03650340.2016.1139086.

Premalatha, R. P., Poorna Bindu, J., Nivetha, E., Malarvizhi, P., Manorama, K., Parameswari, E., Davamani, V. (2023): A review on biochar's effect on soil properties and crop growth. Frontiers in Energy Research, 11(June), 1–19. https://doi.org/10.3389/fenrg.2023.1092637.

Rondon, M., Ramirez, A., Hurtado, M. (2004): Charcoal additions to high fertility ditches enhance yields and quality of cash crops in Andean hillsides of Colombia. Colombia: CIAT Annual Report Cali.

Sahoo, S. S., Vijay, V. K., Chandra, R., Kumar, H. (2021). Production and characterization of biochar produced from slow pyrolysis of pigeon pea stalk and bamboo. Cleaner Engineering and Technology. 3: 100101. https://doi.org/10.1016/j.clet.2021.100101.

Schneider, F., Haderlein, S. B. (2016): Potential effects of biochar on the availability of phosphorus - Mechanistic insights. Geoderma. 277: 83–90. https://doi.org/10.1016/ j.geoderma.2016.05.007.

Shetty, R., Prakash, N. B. (2020): Effect of different biochars on acid soil and growth parameters of rice plants under aluminium toxicity. Scientific Reports. 10(1): 1–11. https://doi.org/10.1038/s41598-020-69262-x.

Singh, B. P., Hatton, B. J., Singh, B., Cowie, A. L., Kathuria, A. (2010): Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils. Journal of Environmental Quality. 39: 1224–1235. https://doi.org/10.2134/jeq2009.0138.

Smider, B., Singh, B. (2014): Agronomic performance of a high ash biochar in two contrasting soils. Agriculture, Ecosystems and Environment. 191: 99–107. https://doi.org/10.1016/j.agee.2014.01.024.

Sokchea, H., Preston, T. R. (2011): Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (bio digester effluent). Livestock Research for Rural Development. 23(4): 1-7.

Torabian, S., Qin, R., Noulas, C., Lu, Y., Wang, G. (2021): Biochar: An organic amendment to crops and an environmental solution. AIMS Agriculture and Food. 6(1): 401–405. https://doi.org/10.3934/AGRFOOD.2021024.

Trazzi, P. A., Leahy, J. J., Hayes, M. H. B., Kwapinski, W. (2016): Adsorption and desorption of phosphate on biochars. Journal of Environmental Chemical Engineering. 4: 37–46. https://doi.org/10.1016/j. jece.2015.11.005.

USSL Staff. (1954): Diagnosis and improvement of saline and alkali soils, USDA Handbook No 60. Washington DC.

Vaccari, F. P., Maienza, A., Miglietta, F., Baronti, S., Di Lonardo, S., Giagnoni, L., Lagomarsino, A., Pozzi, A., Pusceddu, E., Ranieri, R. (2015): Biochar stimulates plant growth but not fruit yield of processing tomato in a fertile soil. Agriculture, Ecosystems & Environment. 207: 163–170. https://doi.org/10.1016/j.agee.2015.04.015.

Xiao, Q., Zhu, L.-X., Zhang, H.-P., Li, X.-Y., Shen, Y.-F., Li, S.-Q. (2016): Soil amendment with biochar increases maize yields in a semi-arid region by improving soil quality and root growth. Crop and Pasture Science. 67(5): 495–507.

Xu, G., Shao, H., Zhang, Y., Junna, S. (2018): Non additive effects of biochar amendments on soil phosphorus fractions in two contrasting soils. Land Degradation and Development. 29: 2720–2727. https://doi.org/10.1002/ldr.3029.

Zubir, M. N., Sam, N. S. M., Ghani, N. S. A. Ismail, A. A. (2020): Growth performance of pineapple (*Ananas comosus* Var. MD2) with different application of granular 995 fertilizer on tropical peat soil. International Journal of Agriculture, Forestry and Plantation, 10:ISSN 2462-1757.