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Research Article

Evaluation of biochar from tea pruning residue and tea fluff compost utilization to alleviate soil chemical properties on an Inceptisol

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Abstract

The inorganic fertilizer that is used excessively in tea plantations causes soil health degradation. Tea pruning residue and tea fluff are local biomass that has the potential to be used as alternatives to soil nutrient input that is not well conducted in the tea plantation. This study evaluated biochar from the residue of tea pruning and tea fluff compost as potential organic materials to improve the chemical properties of soil in tea plantations. The tea pruning residue biochar and tea fluff compost were mixed in Inceptisols in a pot experiment with treatment combinations of A = control, B = 2.5 t manure compost ha^{-1}, C= 0.25% biochar + 1 t tea fluff compost ha^{-1}, D = 0.50% biochar + 1 t tea fluff compost ha^{-1}, E= 0.75% biochar + 1 t tea fluff compost ha^{-1}, F = 0.25% biochar + 1 t tea fluff compost ha^{-1} + 2.5 t manure compost ha^{-1}, G = 0.50% biochar + 1 t tea fluff compost ha^{-1} + 2.5 t manure compost ha^{-1}, and H = 0.75% biochar + 1 t tea fluff compost ha^{-1} + 2.5 t manure compost ha^{-1}. Soil incubation was conducted for 90 days, and soil samples were analyzed for pH, organic C, available P, exchangeable Mg, and exchangeable K contents. The results showed that the mixture of 0.50% biochar + 1 t tea fluff compost ha^{-1} + 2.5 t manure compost ha^{-1} gave the most optimal improvement in soil properties. The improvement percentages of soil properties obtained were available P of 334%, exchangeable Mg of 38%, exchangeable K of 244% and pH of 4.6.

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Introduction

The worldwide uncertainty and the global crisis caused by the Covid-19 pandemic and the Russian invasion of Ukraine caused various price increases for multiple commodities, including fertilizer. The news from NPR article reported that Russia was the primer nitrogen fertilizer exporter that impacted the limitation of fertilizer export, so the price was increased, even nearly five times higher (NPR, 2022). The recent scarcity of non-subsidized fertilizers was triggered by the rise in the price of the raw materials for making inorganic fertilizers. This scarcity of non-subsidized fertilizers is reinforced by the trend of increasing the value of imported fertilizers. In Indonesia, Imports of inorganic fertilizers are dominated by China, followed by Canada and Russia, where the volume of imports in 2020 from each country is 2.4 million tons, 1.26 million tons and 0.96 million tons (BPS, 2021).

The scarcity of fertilizers certainly impacts farmers, especially in the estate plantation sector. Tea plantations are one of the contributors to the country's foreign exchange, with an export value in 2018 reaching 108.5 million USD, where the coverage area of smallholder plantations is around 35% (BPS, 2019). Tea plantations were included in the affected commodity by the scarcity of fertilizers, so there is a potential to decrease production and income from this sector. Moreover, the intensive use of inorganic fertilizers in the plantation causes land degradation, which impacts the effect of "fertilizer dependency" on the soil and plants.

Organic matter is one of the factors that can improve soil properties to reduce the impact of residues and soil degradation due to the use of inorganic inputs. Organic matter itself is part of the soil that can come from the decomposition of plants, animals, and microbial cells (Gebreyes, 2019). Organic matter has a role in providing nutrients, either directly because it contains nutrients needed by plants or indirectly. Indirectly, organic matter can improve soil physical properties such as soil structure, aggregation and reduce soil compaction so that aeration, water absorption and plant root growth are more optimal (Weil and Brady, 2017). Furthermore, organic matter is closely related to helping the growth of soil microbes that act as bioagents providing nutrients in the soil (Weil and Brady, 2017; Gebreyes, 2019).

It is necessary to carry out mitigation efforts in dealing with the scarcity and dependency of these inorganic fertilizers. Utilization of local natural resources and optimization of organic waste is one of the efforts to mitigate fertilizer scarcity. The lack of organic matter input is the main target to improve soil health in tea plantations. In the aspect of cultivation, tea plantations have the potential to contribute local organic matter inputs, both from the field practical activities and the tea post-processing.

One of the tea cultivation activities is pruning. The tea pruning is done every four years, leaving a plant height of 50 cm from the soil surface to the top end of the stem. The pruning aims to maintain the height of the plucking area and rejuvenate the plant. The pruning usually leaves the remaining branches directly placed at the bottom of the pruned tea plant. It aims to supply and return plant nutrients to the soil, but returning these nutrients will be slow due to its come from rough organic matter dominated by stem branches. The long decomposition rate causes delays in the return of nutrients to the soil, while the harvesting of tea is quite intensive, even once a month.

Optimizing the utilization of this organic material could be done by processing the material into activated charcoal or known as biochar. Biochar is a byproduct that results from the combustion process with the absence of oxygen (pyrolysis) at a certain temperature and time from organic materials (Ding et al., 2016). In general, biochar contains high organic C and other inorganic elements such as nitrogen (N), phosphorus (P), potassium (K), aluminium (Al), silicate (Si) (Wang et al., 2012; Anawar et al., 2015; Xu and Fang, 2015). The application of biochar to soil is known to increase the cation exchange capacity (CEC) of the soil, thereby increasing the ability of the soil to retain nutrients and improve the soil structure so that it becomes more friable and porous, which increases the water holding capacity (Haider et al., 2022). From a soil biology aspect, biochar could be used as an energy source that plays a role in solubilizing nutrients in the soil (Grossman et al., 2010; Haider et al., 2022).

Apart from pre-harvest activities, other sources of organic matter could be obtained from post-harvest or tea processing. Generally, tea processing would produce waste in the form of tea powder. This waste biomass comes from the leaf bones and looks like fluff, so it is called tea fluff. Tea fluff accounts for about 2-4% of the total production in tea factories (Chowdhury et al., 2016). In 2020, the made tea production reached 126,000 tons in Indonesia. Utilization of tea fluff as compost could provide some plant nutrients and improve the roots growth of tea plants in the long term (Abo-Sedera, 2016; Wulansari et al., 2020). Based on Wulansari et al. (2020) study, it was found that the fluff compost had a nutrient content of total N 1.75-1.84%, organic-C 18-21%, C/N ratio of 10-12 and pH 7.15-7.68.

The research reported by Widayat et al. (2002) showed that the application of tea factory processing waste (tea fluff) to immature tea plants in Sri Lanka gave the best growth results compared to other organic materials. This shows that tea fluff compost contributes nutrients to the soil (Wulansari et al., 2021). Decomposition of organic matter from tea fluff also produces organic acids such as citric, oxalic, tartaric, malic and malonic acids, which act as metal elements chelators such as iron (Fe) and Al resulting in the release of Fe-P and Al-P chelation which could further increase the availability of P in the Soil (Zúñiga-Silgado et al., 2020). Therefore, evaluating the biochar from tea plant pruning and tea fluff compost utilization was crucial for its potential to regenerate soil fertility and mitigate fertilizer scarcity in tea plantations.

Materials and Methods

Application of biochar from tea pruning residue and tea fluff compost was conducted in a screen house, Soil and Plant Nutrition Laboratory, Research Institute for Tea and Cinchona (RITC). The experiment was carried out for four months, from November 2021 to February 2022.

Biochar and tea fluff compost preparation

The biochar material from tea pruning residue was taken from RITC tea plantation. The biochar was made by crushing pruning branch residue using a Wood Crusher. The refined material was subsequently done pyrolysis at a temperature of 500-600 ºC for 7 hours. The results of laboratory analysis showed that the tea pruning residue biochar had the following characteristics: pH H_2O = 8.2, organic C = 6.13%, total N = 0.99%, available P = 44.8 ppm, exchangeable K = 2.28 cmol kg^{-1}, exchangeable Mg = 0.56 cmol kg^{-1}, and water content = 2.3 %.

Tea fluff waste was obtained from RITC green tea factory. Tea fluff and cow manure were mixed with

EM-4 decomposer solution that contained microbial decomposer, consisting of *Lactobacillus* sp., *Rhodopseudomonas* sp., *Actinomycetes* sp., *Streptomycetes* sp., and yeast. These ingredients combination were then added with tap water until the condition is mack or the water content reaches 30-40% with the characteristics of the material mixture having plastic properties when clenched by hand. The compost material was put into a compost bin (1 x 1 x 1 m) gradually until it reached a height of 15-20 cm. The compost bin was then covered with plastic and anaerobic incubation was carried out for 21 days. During the compost incubation, temperature and humidity observations were carried out and the compost material was turned over. Ready-to-use tea fluff compost was characterized by an odorless aroma, optimal humidity ranging from 40-50% and temperatures reaching 30-40 °C. Results of laboratory analysis showed that the tea fluff compost had the following characteristics: pH H_2O = 7.15, organic C = 18.1%, total N = 1.75%, and C/N ratio = 10.5.

Soil medium preparation

An Inceptisol was used as the soil medium originating from Block B6 of RITC experimental field with the dominant plant composition being GMB 7 clone. The GMB 7 clone was developed by RITC that has the highest productivity potency, around 5.8 t ha^{-1} $year^{-1}$ and has resistance capability from Blister Blight disease and Trips pest. The soil used for the experiment was taken from a depth of 0-30 cm as much as two sacks or around 100 kg. The soil was air-dried for 48 hours and sieved to pass through a 2 mm sieve, and subsequently weighed 1 kg per polybag and put into a 15 x 30 cm polybag. The initial soil properties were as follows: pH H_2O = 4.6, organic C = 2.9%, total N = 0.207%, available P = 3.15 ppm, exchangeable K = 0.272 cmol kg^{-1}, and exchangeable Mg = 0.335 cmol kg^{-1}.

Application and soil incubation preparation

Biochar and compost were sieved using a 0.25 mm sieve and then weighed according to the treatment. The percentage of biochar is measured based on the ratio of the mass of biochar to the mass of the soil, while the compost requirement is calculated based on the mass of the soil. The dose of tea fluff compost used was 1 t ha^{-1}, equivalent to 5 g $polybag^{-1}$ and the dose of manure compost was 2.5 t ha^{-1}, which is equivalent to 12.5 g $polybag^{-1}$. The combination of treatments carried out included A = control, B = 2.5 t ha^{-1} manure compost, C = 0.25% biochar + 1 t ha^{-1} tea fluff compost, D= 0.50% biochar + 1 t ha^{-1} tea fluff compost, E = 0.75% biochar + 1 t ha^{-1} tea fluff compost, F = 0.25% biochar + 1 t ha^{-1} tea fluff compost + 2.5 t ha^{-1} manure compost, G = 0.50% biochar + 1 t ha^{-1} tea fluff compost + 2.5 t ha^{-1} manure compost, H = 0.75% biochar + 1 t ha^{-1} tea fluff compost + 2.5 t ha^{-1} manure compost. The application was made by mixing biochar and compost with soil in polybags until homogeneous. The eight treatments were arranged in a randomized block design with three replications for each treatment.

Maintenance and observation

Soil incubation was carried out for 90 days. Maintenance was carried out during the incubation period, including monitoring soil temperature and humidity. If soil moisture reached <40%, watering was carried out until the soil was moist again. Soil sampling was carried out on the initial soil before application and 90 days after incubation. Parameters of observations made were organic C using the Walkley and Black method (FAO, 2019), pH using the electrode method (ISRIC, 1993), available P using the Bray I method (ISRIC, 1993), exchangeable K and Mg using ammonium acetate extraction method (ISRIC, 1993).

Statistical analysis

Data obtained were subjected to the Analysis of Variance (ANOVA) followed by the Duncan's Multiple Range Test (DMRT) with α = 5% to test the differences between treatments. Data analysis was carried out with the support of SPSS Version 26 software.

Results and Discussion

Effect of biochar and tea fluff compost on soil pH and organic C

The combined application of tea pruning residue biochar and tea fluff compost did not significantly affect the soil reaction, but there was a significant effect on the Soil organic C content (Table 1). The results showed potential for increasing the pH of the Inceptisol studied when the tea pruning residue biochar and tea fluff compost was applied. A high increase in soil organic C was shown in the application of 0.75% and 0.50% tea pruning residue biochar with a mixture of 1 t tea fluff compost ha^{-1} and 2.5 t manure compost ha^{-1} with an increase of 39.1% and 24% against the control (Table 2).

Tea pruning residue biochar and tea fluff compost are thought to contribute to the increase in organic C content as a result of the decomposition of the soil conditioners. The application of tea pruning residue biochar and tea fluff compost on Inceptisols gave a more optimum soil reaction for tea plants in the range of 4.5-5.5 (Syakir, 2010). The organic matter content that has been decomposed from the composting process of tea fluff waste could supply organic C in the soil because the soil has relatively low to moderate organic matter. Inceptisols are mineral soils with a recent pedogenesis process, often called immature soils, so the organic matter in this soil is relatively minimal. Furthermore, the pyrolysis process carried out on the tea pruning residue could provide more readily available organic C.

Table 1. The effect of tea pruning residue and tea fluff compost on soil pH and organic C.

Treatments	pH	Organic-C (%)
Control	4.28 ± 0.35 a	2.04 ± 0.03 a
2.5 t ha^{-1} MC	4.60 ± 0.26 a	2.10 ± 0.13 a
0.25% BC + 1 t ha^{-1} FC	4.60 ± 0.12 a	2.51 ± 0.12 ab
0.50% BC + 1 t ha^{-1} FC	4.67 ± 0.21 a	2.09 ± 0.23 a
0.75% BC + 1 t ha^{-1} FC	4.53 ± 0.15 a	2.39 ± 0.12 ab
0.25% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	4.63 ± 0.31 a	2.40 ± 0.31 ab
0.50% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	4.60 ± 0.10 a	2.53 ± 0.55 ab
0.75% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	4.50 ± 0.10 a	2.84 ± 0.08 b

Remarks: The value (mean ± standard deviation) followed with a different letter showed a significant difference with P value ≤ 0.05. BC = tea pruning residue biochar; FC = tea fluff compost; MC = manure compost.

Table 2. Improvement percentage of soil pH and organic C compared to control.

Treatments	Improvement percentage compared to control	
	pH	Organic C
Control	-	-
2.5 t ha^{-1} MC	7.8%	3.1%
0.25% BC + 1 t ha^{-1} FC	7.8%	22.9%
0.50% BC + 1 t ha^{-1} FC	9.4%	2.3%
0.75% BC + 1 t ha^{-1} FC	6.2%	17.3%
0.25% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	8.6%	17.8%
0.50% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	7.8%	24.0%
0.75% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	5.5%	39.1%

Remarks : BC = tea pruning residue biochar; FC = tea fluff compost; MC = manure compost.

Tea pruning residue consisting of twigs and stems of tea plants is thought to decompose slowly so that the process of releasing nutrients will be slow. Twigs, branches and stems of tea plants have a dominant lignin content which is difficult to decompose (Semenov et al., 2019). In the decomposition process, microbial decomposers will generally decompose lignin material first, than other materials, so the higher the lignin content, the longer the decomposition process will take (Rahman et al., 2013). The increment trend of pH and organic C was in line with the report from Nigussie et al. (2012) that the application of biochar in chromium polluted soil could increase soil pH up to 6,8% and organic C up to 33,6%.

Effect of biochar and tea fluff compost on soil available P, exchangeable K and Mg

The application of tea pruning residue biochar and tea fluff compost showed mixed responses to soil available P, exchangeable K and Mg. The analysis results showed an increasing trend of available P in the soil in the application of biochar and tea fluff compost (Table 3). Applications of 0.25% and 0.50% biochar combined with tea fluff compost showed a decrease in the exchangeable Mg in the soil up to 14.4% compared to control. Still, when combined with manure compost, the nutrient content increased up to 38% compared with control.

Table 3. The effect of tea pruning residue and tea fluff compost on soil available P, exchangeable Mg and K.

Treatments	Available P (ppm)	Exchangeable Mg (cmol kg^{-1})	Exchangeable K (cmol kg^{-1})
Control	0.58 ± 0.26 ab	1.17 ± 0.34 ab	0.43 ± 0.06 a
2.5 t ha^{-1} MC	0.35 ± 0.21 a	1.42 ± 0.17 bc	1.60 ± 0.37 c
0.25% BC + 1 t ha^{-1} FC	0.57 ± 0.23 ab	1.02 ± 0.13 a	0.73 ± 0.11 ab
0.50% BC + 1 t ha^{-1} FC	2.32 ± 0.37 c	1.01 ± 0.19 a	0.58 ± 0.05 ab
0.75% BC + 1 t ha^{-1} FC	1.27 ± 0.50 b	1.28 ± 0.17 abc	0.62 ± 0.08 ab
0.25% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	1.18 ± 0.57 b	1.26 ± 0.27 abc	0.82 ± 0.13 b
0.50% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	2.52 ± 0.46 c	1.62 ± 0.20 c	1.48 ± 0.14 c
0.75% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	5.35 ± 0.48 d	1.51 ± 0.03 c	1.40 ± 0.03 c

Remarks: The value (mean ± standard deviation) followed with a different letter showed a significant difference with P value ≤ 0.05. BC = tea pruning residue biochar; FC = tea fluff compost; MC = manure compost.

Furthermore, the addition of manure compost showed an increase in the K-dd content in the soil up to 244.3% compared to the control (Table 4). The increase in soil organic C has the potential to increase soil microbial activity in the process of dissolving and mineralizing nutrients that subsequently produce some organic acid that could release the chelation of P with metal elements (Mardad et al., 2013). Indigenous phosphate solubilizing microbes are known to produce secondary metabolites in the form of organic acids that play a role in releasing P bond chains with metal elements in the soil (Wong et al., 2015; Pande et al., 2017). An increase in the organic-C as a source of microbial energy in the soil is known to increase the microbial population in the soil and increase the secretory activity of metabolites such as organic acids and phytohormones (Hussain et al., 2022; Vocciante et al., 2022). Moreover, the previous studies indicated that composted black tea fluff exhibits the nutrient properties above Indonesian

Table 4. Improvement percentage of soil available P, exchangeable Mg and K compared to control.

Treatment	Improvement percentage compared to control		
	Available P	Exchangeable Mg	Exchangeable K
Control	-	-	-
2.5 t ha^{-1} MC	-40.2%	21.0%	273.0%
0.25% BC + 1 t ha^{-1} FC	-2.2%	-13.4%	70.9%
0.50% BC + 1 t ha^{-1} FC	300.0%	-14.4%	35.4%
0.75% BC + 1 t ha^{-1} FC	119.5%	9.0%	45.7%
0.25% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	102.9%	7.7%	92.3%
0.50% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	334.0%	38.0%	244.3%
0.75% BC + 1 t ha^{-1} FC + 2.5 t ha^{-1} MC	821.9%	28.9%	227.0%

Remarks : BC = tea pruning residue biochar; FC = tea fluff compost; MC = manure compost.

Standard quality of organic fertilizer, and also the addition of organic manure in the tea fluff could produce better compost nutrients (Wulansari et al., 2020). The decrease in exchangeable Mg in the soil when biochar and tea fluff compost was added is due to the antagonistic behavior between Mg and K elements. Furthermore, it has a significant correlation between exchangeable K and Mg (R = 0.69), which indicates these elements have a complex interaction in the soil solution. In the control treatment, the K nutrient content of the soil was very low, and when tea pruning residue biochar and tea fluff were applied, which had higher K than control, its exhibited K-Mg competition. The elements of Mg and K are known to have antagonistic behavior, where there would be competition with anions in the soil or the biochar (Xie et al., 2021). The K ion has one valence electron (K^+), which has a weaker affinity when compared to the Mg ion, which has two valence electrons (Mg^{2+}) (Chaudhry et al., 2021). Furthermore, the imbalance in the ratio of K and Mg will also have an impact on absorption by plant roots, where the element Mg will be absorbed when the concentration of K^+ is lower and will be inhibited when the concentration of K^+ is high (Xie et al., 2021). Mg absorption will be inhibited if the concentration of K^+ is more than 20 mol L^{-1} (Shaul, 2002). Furthermore, the K and Mg elements would be easily leached if they cannot be properly bound in the soil solution (Gransee and Führs, 2013). The research from Tito et al. (2020) showed that the application of 5 t ha^{-1} biochar from poultry litter improved soil chemical properties, especially for available P and exchangeable K in the soils, which were in line with the results of this experiment. The addition of manure compost as a soil conditioner showed that it could support the nutrient balance and increment in the soil. Manure compost was thought to be able to add K and Mg elements to the soil. Nutrients present in manure are thought to be able to enrich soil biota and improve more stable soil structure. The most optimum composition of soil conditioner that could be applied in Inceptisols of tea plantations was 0.5% tea pruning residue biochar with the addition of 1 t ha^{-1} of tea fluff compost and 2.5 t ha^{-1} of manure compost.

Conclusion

Biochar from tea pruning residue and tea fluff compost shows the potential to be used as soil ameliorant as a step to mitigate fertilizer scarcity, especially for tea plantations. Application of 0.50% tea pruning residue biochar with a mixture of 1 t ha^{-1} of tea fluff compost and 2.5 t ha^{-1} of manure compost showed optimum results for improving soil properties with increment percentages in available P of 334%, exchangeable Mg of 38%, and exchangeable K of 244%. The treatment combination produced the optimum pH of 4.6 for tea plants grown on Inceptisols.

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References

Abo-Sedera, F. 2016. Effect of organic fertilizer and foliar spray with some safety compounds on growth and productivity of snap bean. *Annals of Agricultural Science, Moshtohor* 54(1):105-118, doi:10.21608/assjm.2016.103931.

Anawar, H.M., Akter, F., Solaiman, Z.M. and Strezov, V. 2015. Biochar: an emerging panacea for remediation of soil contaminants from mining, industry and sewage wastes. *Pedosphere* 25:654-665, doi:10.1016/S1002-0160(15)30046-1.

BPS. 2019. Tea Statistics of Indonesia 2018. Central Bureau of Statistics, Indonesia (*in Indonesian*).

BPS. 2021. Fertilizer imports by the main country of origin, 2000-2020. Central Bureau of Statistics. Retrieved April 27, 2022, from https://www.bps.go.id/statictable/2014/09/08/1044/impor-pupuk-menurut-negara-asal-utama-2000-2016.html (*in Indonesian*).

Chaudhry, A.H., Nayab, S., Hussain, S.B., Ali, M. and Pan, Z. 2021. Current understandings on magnesium deficiency and future outlooks for sustainable agriculture. In *International Journal of Molecular Sciences* 22(4):1-18, doi:10.3390/ijms22041819.

Chowdhury, A., Sarkar, S., Chowdhury, A., Bardhan, S., Mandal, P. and Chowdhury, M. 2016. Tea waste management: a case study from West Bengal, India. *Indian Journal of Science and Technology* 9(42):1-6, doi:10.17485/ijst/2016/v9i42/89790.

Ding, Y., Liu, Y., Liu, S., Li, Z., Tan, X., Huang, X., Zeng, G., Zhou, L. and Zheng, B. 2016. Biochar to improve soil fertility. A review. *Agronomy for Sustainable Development* 36:36, doi:10.1007/s13593-016-0372z.

FAO. 2019. Standard operating procedure for soil organic carbon Walkley-Black method. Rome.

Gebreyes, G. 2019. Soil organic matter and its role in soil health and crop productivity improvement. *Academic Research Journal of Agricultural Science and Research* 7(7):475-483, doi:10.14662/ARJASR2019.147.

Gransee, A. and Führs, H. 2013. Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. *Plant and Soil* 368(1–2):5–21, doi:10.1007/s11104-012-1567-y.

Grossman, J.M,, O'Neill. B.E., Tsai, S.M., Liang, B., Neves, E., Lehmann, J. and Thies, J.E. 2010. Amazonian anthrosols support similar microbial' communities that differ distinctly from those extant in adjacent, unmodified soils of the same mineralogy. *Microbial Ecology* 60:192-205, doi:10.1007/s00248-010- 9689-3.

Haider, F.U., Coulter, J.A., Cai, L., Hussain, S., Cheema, S.A., Wu, J. and Zhang, R. 2022. An overview on biochar production, its implications, and mechanisms of biochar-induced amelioration of soil and plant characteristics. *Pedosphere* 32(1):107-130, doi:10.1016/S1002-0160(20)60094-7.

Hussain, A., Iqbal, Z., Aurangzaib, M., Naeem, M., Mustafa, S., Shoaib, M. and Khalid, M. 2022. Comparative effectiveness of plant growth promoting rhizobacteria and various organic carriers on wheat growth, physiology, antioxidative activities and rhizosphere properties. *Pakistan Journal of Botany* 54(1):1-8, doi:10.30848/pjb2022-1(43).

ISRIC. 1993. Procedures for Soil Analysis. In: van Reeuwijk, L.P. (Ed.) *Technical Paper.* International Soil Reference and Information Centre. Wageningen, The Netherlands. 4th ed.

Mardad, I., Serrano, A. and Soukri, A. 2013. Solubilization of inorganic phosphate and production of organic acids by bacteria isolated from a Moroccan mineral phosphate deposit. *African Journal of Microbiology Research* 7(8):626-635, doi:10.5897/AJMR12.1431.

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

NPR. 2022. Russia-Ukraine war worsens fertilizer crunch, risking food supplies. Retrieved April 27, 2022, from https://www.npr.org/2022/04/12/1092251401/russia-ukraine-war-worsens-fertilizer-crunch-risking-food-supplies.

Pande, A., Pandey, P., Mehra, S., Singh, M. and Kaushik, S. 2017. Phenotypic and genotypic characterization of phosphate solubilizing bacteria and their efficiency on the growth of maize. *Journal of Genetic Engineering and Biotechnology* 15(2):379–391, doi:10.1016/j.jgeb.2017.06.005.

Rahman, M.M., Tsukamoto, J., Rahman, Md.M., Yoneyama, A. and Mostafa, K.M. 2013. Lignin and its effects on litter decomposition in forest ecosystems. *Chemistry and Ecology* 29(6):540-553, doi:10.1080/02757540. 2013.790380.

Semenov, V.M., Pautova, N.B., Lebedeva, T.N., Khromychkina, D.P., Semenova, N.A. and Lopes de Gerenyu, V.O. 2019. Plant residues decomposition and formation of active organic matter in the soil of the incubation experiments. *Eurasian Soil Science* 52(10):1183-1194, doi:10.1134/S1064229319100119.

Shaul, O. 2002. Magnesium transport and function in plants: the tip of the iceberg. *Biometals* 15:307-321, doi:10.1023/A:1016091118585.

Syakir. 2010. Tea cultivation and post-harvest. Ministry of Agriculture of Indonesia 65. https://books.google.co.id/books/about/Teh_Budidaya_Pengolahan_Pascapanen.html?id=KGXjfmDxo28C&redir_esc=y (*in Indonesian*).

Tito, G.A., Garófalo Chaves, L.H., Dantas, E.R.B., de Souza Laurentino, L.G., de Souza, F.G., and Guerra, H.O.C. 2020. Biochar on soil chemical properties and beak pepper (*Capsicun chinense*) production. *Agricultural Sciences* 11(12):1133-1142, doi:10.4236/as.2020.1112074.

Vocciante, M., Grifoni, M., Fusini, D., Petruzzelli, G. and Franchi, E. 2022. The role of plant growth-promoting rhizobacteria (PGPR) in mitigating plant's environmental stresses. *Applied Sciences (Switzerland)* 12(3):1231, doi:10.3390/app12031231.

Wang, H., Feng, L and Chen, Y. 2012. Advances in biochar production from wastes and its applications. *Chemical Industry and Engineering Progress* 63:3727-3740.

Weil, R.R. and Brady N.C. 2017. Soil organic matter. *Nature and Properties of Soils* (15th ed). Pearson Education Limited, England, 545-601.

Widayat, W., Rayati, D.J., Arifin, I.S., Sudjatmoko and Suherman, O. 2002. Optimization of tea fields by inoculation of Mycorrhizal Arbuscula fungi and provision of pluff compost in order to support organic farming. Research Institute for Tea and Cinchona, Research Report (VII-2): 203-210.

Wong, W.S., Tan, S.N., Ge, L., Chen, X. and Yong, J.W.H. 2015. The Importance of Phytohormones and Microbes in Biofertilizers. In: Maheshwari, D.K. (ed.). *Bacterial Metabolites in Sustainable Agroecosystem, Sustainable Development and Biodiversity* 12. doi:10.1007/978-3-319-24654-3_6.

Wulansari, R. and Rezamela, E. 2020. Effect of black tea waste compost (tea fluff) on growth of tea seed (*Camellia sinensis* (L.) Kuntze). *Jurnal Tanah dan Sumberdaya Lahan* 7(2): 341-350, doi:. 10.21776/ub.jtsl.2020 (*in Indonesian*).

Wulansari, R., Yuniarti, A. and Setiawaty, M.R. 2021. Evaluation growth of tea seedling and population of *Azotobacter sp.* from application compost of green tea factory waste (tea fluff) and *Azotobacter sp.* on Andisols. *International Journal of Natural Resource Ecology and Management* 6(3):156-162, doi:10.11648/j.ijnrem.20210603.17.

Xie, K., Cakmak, I., Wang, S., Zhang, F. and Guo, S. 2021. Synergistic and antagonistic interactions between potassium and magnesium in higher plants. *Crop Journal* 9(2):249-256, doi:10.1016/j.cj.2020.10.005.

Xu, Y. and Fang, Z. 2015. Advances on remediation of heavy metal in the soil by biochar. *Environmental Engineering* 33:156-159.

Zúñiga-Silgado, D., Rivera-Leyva, J.C., Coleman, J.J., Sánchez-Reyez, A., Valencia-Díaz, S., Serrano, M., De-Bashan, L.E., and Folch-Mallol, J.L. 2020. Soil type affects organic acid production and phosphorus solubilization efficiency mediated by several native fungal strains from Mexico. *Microorganisms 8*(9):1-17, doi:10.3390/microorganisms8091337.