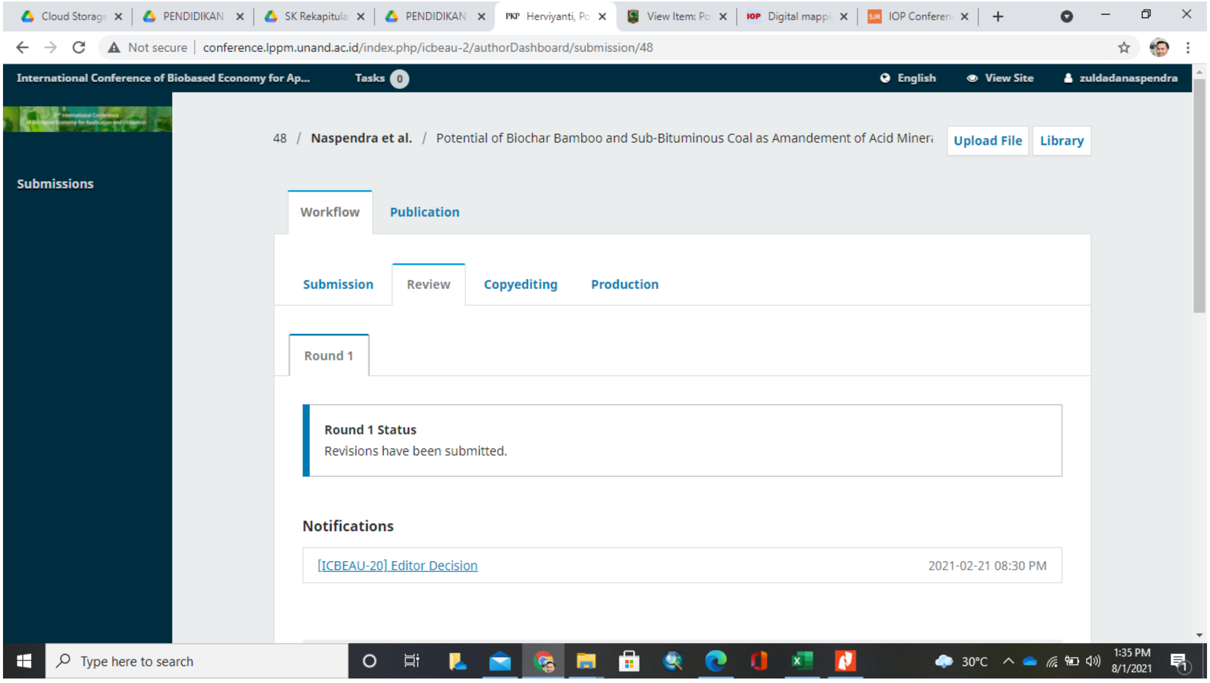
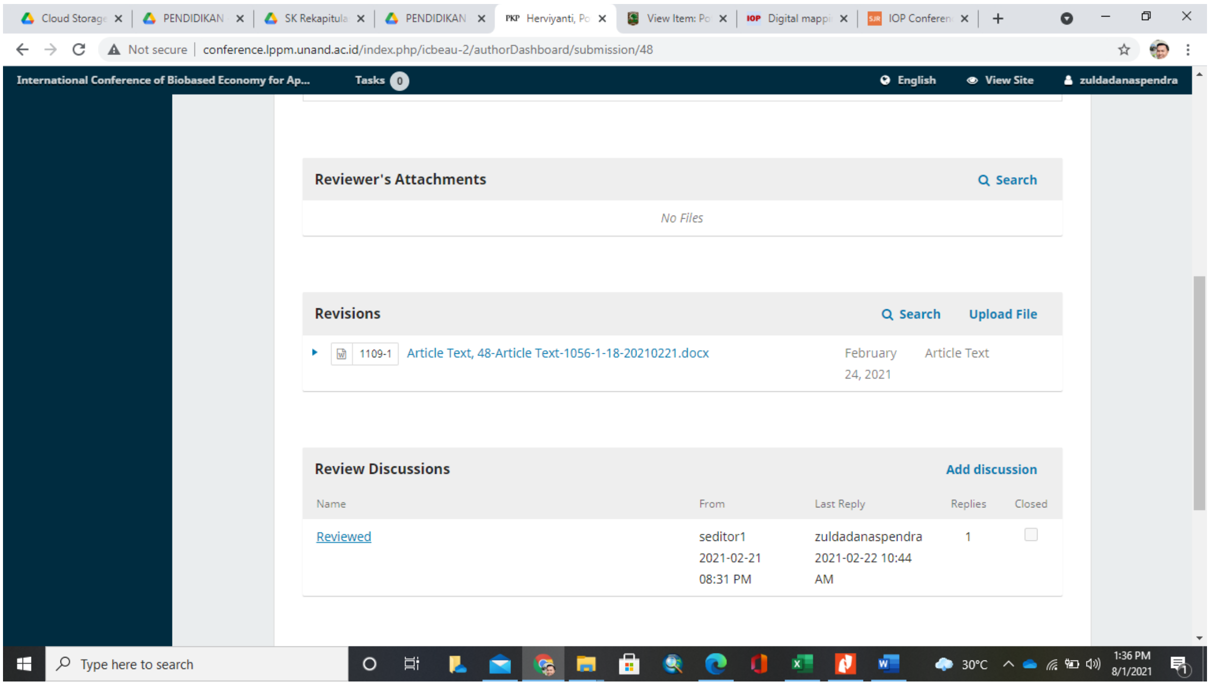
Peer Review Article





Potential of biochar bamboo and sub-bituminous coal as amendment of acid mineral soils for improving the growth of arabica coffee (*Coffea arabica l.*) seedlings

Abstract. Improvement the characteristics of acid mineral soil (Ultisols) is needed to support plant productivity. However, the utilization of biochar combined with sub-bituminous in improving ultisol is still limited. Therefore, this research was conducted by using treatments: 1) Control 0% Sub-bituminous (SBC) + 0% Bamboo Biochar (B); 2) 100% SBC (20 ton.ha^{-1}); 3) 75% SBC + 25% B; 4) 50% SBC + 50% B; 5) 25% SBC + 75% B; and 6) 100% B (20 ton.ha-1). This study was designed using Completely Randomized Design (CRD) with 3 replications. The results showed that the application of combined biochar and sub-bituminous had a significant effect in improving ultisol's fertility characteristics. There are two treatments that provide the most significant results for improving soil properties, namely 100% sub-bituminous treatment with a significant effect in increasing pH (1.3 pH units), Organic carbon (3.34%), Total N (0.12%), CEC (10.87 cmol/kg and Ca^{2+} (1.2%). However, 50% sub-bituminous + 50% bamboo biochar treatment have a significant effect in increasing Available P (1.1 ppm), CEC (9.04 cmol/kg K^{+} (0.51 cmol/kg), Ca^{2+} (1.37 cmol/kg), and Mg^{2+} (1.27 cmol/kg). In addition, application of 50% sub-bituminous + 50% bamboo biochar gave the best result for the plant height, branches and leaves of the coffee plants.

Keywords: bamboo, biochar, coffee, sub-bituminous, ultisols.

1. Introduction

Acid mineral soils are widespread in some areas in Indonesia. One of the most extensive acid soil orders is Ultisol, which occupies 45,794 ha or 25% of the total land area of Indonesia [1]. Ultisol belongs to highly weathered soils. Ultisol has characteristic acidic pH and high Al saturation [1].

Ultisols are generally cultivated for various plantation commodities. One of commodities that achieved excellence in local and international trading, is coffee. Coffees have been popular in recent years and have grown in more than 80 countries in the world. However, the productivity of Indonesian coffee is only 0.6 tons.ha^{-1} [2], compared to the potential production reach 3 tons.ha^{-1}.

Some attempts to increase coffee productivity need to be established. One of the eco-friendly technology that can be used is bamboo biochar as a source of ameliorant materials. Bamboo lands in Indonesia occupy an estimated area of 2.1 million ha [3]. Numerous studies have revealed that biochar can improve soil physical and chemical properties due to biochar has a high surface area, pore structure, alkaline cations, and a medium-high CEC [4,5,6,7,8]. However, there is a limitation in researches regarding the influence of bamboo biochar on ultisol characteristics and coffee plant growth.

Also, several previous types of research indicated that biochar can be combined with other materials to improve soil properties [9,10,11]. One of the potential combination is sub-bituminous. The sub-bituminous is a type of lower grade coal containing high humic compounds, high negative charge and higher CEC than clay [12, 13]. However, research on examining the combination of biochar and sub-bituminous in improving the ultisol properties and the growth of coffee plants are still limited. Therefore, this research aimed to: a) study the potential and effect of the combination of bamboo biochar and sub-bituminous coal on the chemical properties of Ultisols, and b) obtain the best combination formula on the growth of arabica coffee in the seedling stage.

2. Method

This research was conducted from April to November 2020, located in Rumah Kawat, Faculty of Agriculture, Universitas Andalas. The steps were first making bamboo biochar, then followed by preparing the sub-bituminous, and ultisols as growing media. The bamboo biochar was pyrolyzed by using the conventional reactor method made by metal cylinder. Sub-bituminous was obtained from Nagari Ganggo Mudiak, Bonjol, Pasaman, at 1-2 m depth. However, ultisols as growing media were obtained from Experimental Garden, Faculty of Agriculture, Universitas Andalas which was taken from 0-20 cm depth.

The experimental design used in this study was CRD (Completely Randomized Design) with 3 replications. The treatment was implemented in polybag with equivalent dose: 1) Control 0% Sub-bituminous (SBC) + 0% Biochar Bamboo (B)., 2) 100% SBC (20 $ton.ha^{-1}$)., 3) 75% SBC + 25% B., 4) 50% SBC + 50% B., 5) 25% SBC + 75% B, and 6) 100% B (20 $ton.ha^{-1}$). Water was added in order to reach the field capacity. Subsequently, all treatments were incubated for 15 days. The next step was taking a soil sample to be analyzed in the laboratory.

Arabika coffee seedlings used in this study was 4 months old that grew evenly. After that, the seeds were moved to each treatment carefully where one polybag contained one plant. The types of fertilizers used were Urea, SP-36, and Potassium Chloride (KCl), while the fertilizer dosage was based on the recommendation from ICCRI [14]. The first fertilization was 20g Urea; 10g SP-36 and 10g KCl, and the second fertilization was conducted 3 months after transplanting the seeds (30g Urea; 15g SP-36 and 15g KCl). Other nursing procedures were implemented based on the best recommendations from ICCRI [14].

Soil analysis consisted of pH, Exch Al, CEC [15], base cations Ca, Mg, K, available P, Organic carbon [16], and Total N. The plant height, number of leaves, and number of branches were measured and counted every week for 28 weeks. All treatments were analyzed statistically using the F test. If F calculated is more significant than F Table at 5% level, it will be followed by Duncan's New Multiple Range Test (DNMRT) test at 5% level.

3. Result and Discussion

3.1 The Effect of Sub-bituminous and Biochar in Improving Soil Chemical characteristics.

Table 1 shows two formulations that significantly influence soil properties, namely 100% sub-bituminous treatment and 50% sub-bituminous + 50% bamboo biochar treatment. Both treatments significantly affect the five (5) soil properties, such as pH, Organic carbon, Total N, CEC, and Ca in 100% sub-bituminous treatment and available P, CEC, K, Ca, Mg in treatment 50 % sub-bituminous + 50% B. This indicates that 50% sub-bituminous + 50% bamboo biochar can substitute the use of 100% sub-bituminous.

Table 1. Chemical properties of Ultisol with several experimental treatments

Treatments	**pH H_2O**	**Available P** (ppm)	**Organic C** (%)	**Total N** (%)	**CEC** (cmol/kg)	**Base Cation** (cmol/kg) **K**	**Ca**	**Mg**	**Exch Al** (cmol/kg)
Control	4.17 f	5.25 d	0.40 f	0.36 c	10.11 d	0.66 c	1.41 b	1.78 c	3.19
100% of Sub-bituminous coal (SBC)	5.47 a	6.35 c	3.74 a	0.48 a	20.98 a	1.03 b	2.61 a	2.34 bc	nd
75% SBC + 25% B	4.84 c	6.52 bc	3.30 b	0.46 ab	17.10 b	1.10 ab	2.87 a	2.77 ab	nd
50% SBC + 50% B	4.74 d	7.00 a	1.63 c	0.45 ab	19.15 a	1.17 a	2.78 a	3.05 a	nd
25% SBC + 75% B	4.66 e	6.58 b	1.51 d	0.41 bc	11.78 cd	1.02 b	2.69 a	2.51 ab	nd
100% of Bamboo Biochar (B)	5.3 b	6.4 bc	1.20 e	0.40 bc	12.9 c	1.1 ab	2.7 a	3.14 a	nd

CV	0.82%	1.48%	2.30%	7.22%	6.94%	7.17%	10.50%	14.16%

Notes: - *S = Sub-bituminous coal; B = Bamboo Biochar; nd = undetected*
- The numbers followed by the same letter according to the column is not significantly different according to the DNMRT at level of 5%.

3.1.1. Soil Acidity, available P, and exchangeable Al. A dose of 100% sub-bituminous gave the best results in increasing the pH of ultisols by 1.3 pH units, compared to the control. This increase is in line with the research conducted by Cornellissen et al [17]. The increase of soil pH in sub-bituminous treatment is related to the negative charge of the functional groups of sub-bituminous, while the increase of soil pH on biochar treatment is dominantly caused by base cations released from biochar [18,5,6] as shown in Table 2 (r = 0.636, 0.648, 0.513).

Based on Figure 1, all treatment formulations can reduce exch Al to the minimum level due to the aluminum is chelated by negative charges of functional groups [19]. On biochar treatment, the decrease in aluminum solubility was due to 1) the electrostatic bond between Al and the biochar surface, 2) the exchange of Al with base cations or protons on the biochar surface (r = -0.954 **, -0.987 ** - 0.795, Table 2), and 3) the porous biochar structure and functional groups in the aromatic structure have a strong affinity for adsorbing heavy metals, including aluminum [20,21].

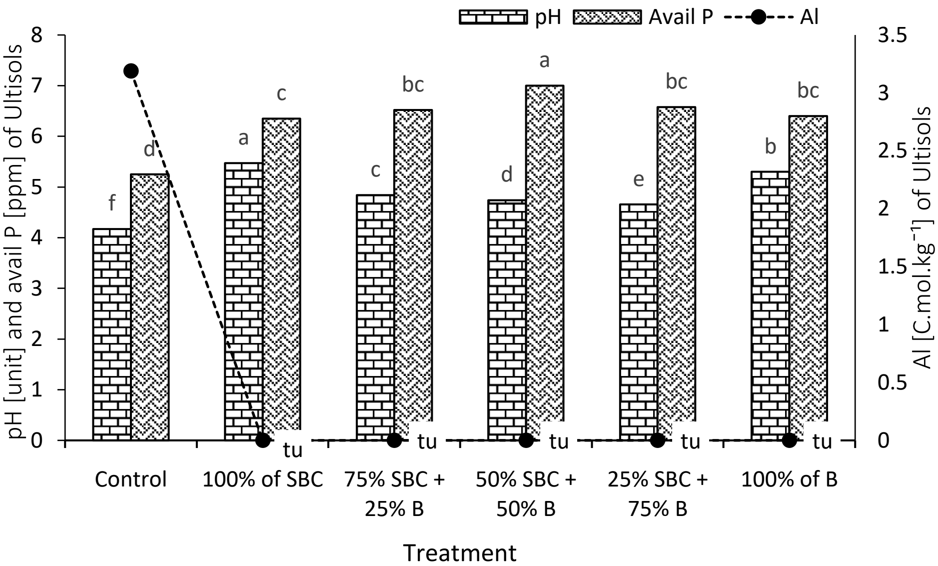


Figure 1. Effect of biochar and sub-bituminous on pH (H_2O), available P, and exch Al.

All treatment increases available P between 1.1 - 1.75 ppm (Table 1). The highest available P content is found in 50% sub-bituminous + 50% bamboo biochar treatment (Figure 1) with increasing by 1.75 ppm from 5.27 to 7 ppm. Sub-bituminous increases available P by preventing the interaction of Al and Fe metals with P through formation of complex or chelate reaction. In biochar treatment, available P can be increased through several mechanisms, such as: 1) Al is absorbed in the biochar structure [20,21], 2) biochar increases soil pH (r = 0.476, Table 2), and 3) biochar is a source of dissolved P [22, 23].

3.1.2 Organic carbon, Total N, and C/N. Figure 2 shows that the application of 100% sub-bituminous treatment increases the soil C-Organic content from 0.4 to 3.74%. Also, the increasing of organic carbon tend to be more dominant in sub-bituminous treatment rather than biochar treatment. It is caused by the sub-bituminous contains > 30% C-Organic [24] as source of soil carbon [25].

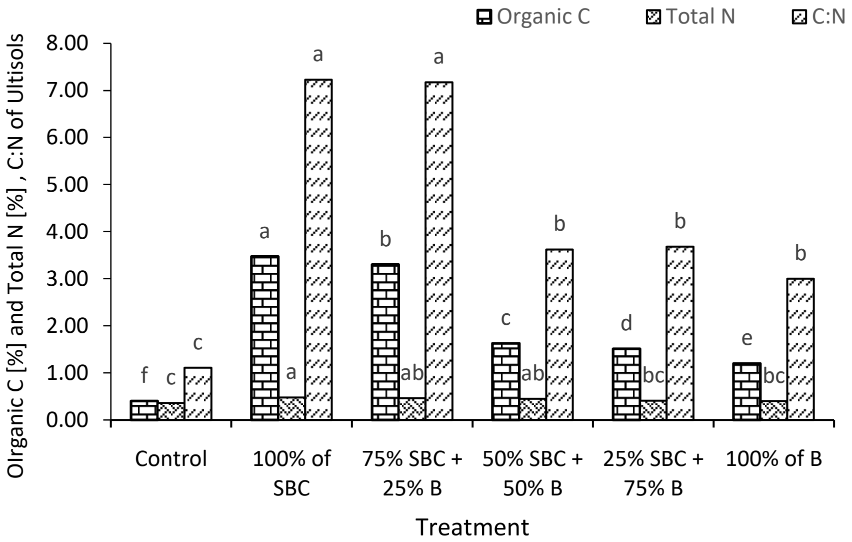


Figure 2. Effect of biochar and sub-bituminous on carbon organic and Total N.

Based on Figure 2, applying 100% biochar did not significantly increase the nitrogen on ultisols. The result is in line with Xu et al [22]. Although it was not significant increasing Total N, it was better than previous research conducted by Herviyanti et al [25] by 0.39. It is due to 1) the N content in sub-bituminous [26] and 2) the carboxyl (-COOH) and phenol (-OH) functional groups in sub-bituminous can complex $N\text{-}NH_4^+$. However, the C:N for each treatment and soil were categorized as low (<7.2). The highest C:N ratio was measured in 100% sub-bituminous treatment by 7.23 and was correlated with Organic carbon content (r = 0.993**, Table 2) and Total N (r = 0.912*, Table 2). It is due to the high carbon content on sub-bituminous. It is in contrast to 100% bamboo biochar treatment with C:N value is 3. This indicates that biochar is more stable in soil [27,28] rather than sub-bituminous.

3.1.3 CEC and Base Cations. Figure 3 shows the CEC of ultisols used as a growing medium in this experiment was low (10.11 cmol/kg). The highest CEC value was found in the 100% sub-bituminous treatment (20.98 cmol/kg) and in the treatment of 50% sub-bituminous + 50% bamboo biochar (19.15 cmol/kg). The good combination in increasing soil CEC indicates that functional groups in both materials are reactive with soil cations. According to Verheijen et al [29], biochar can increase soil CEC due to the reaction between the carboxyl functional groups on the surface of the biochar with water, oxygen, and other compounds in the soil.

The highest increase in base cations (K^+, Ca^{2+}, Mg^{2+}) can be found in 50% sub-bituminous + 50% biochar treatment with 7 cmol/kg, and it is not significantly different to 100% biochar treatment with 6.94 cmol/kg (Figure 3). This indicates that the biochar and sub-bituminous can be combined as amendment to increase base cations.

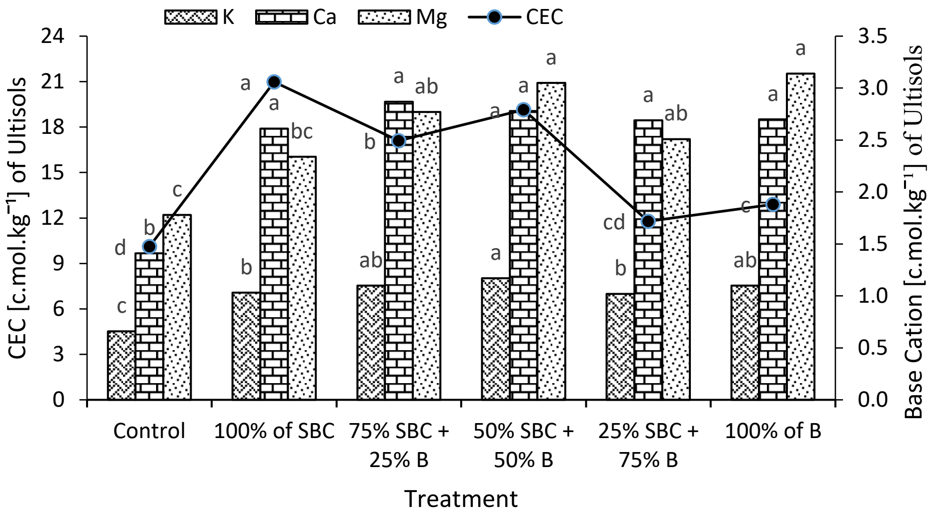


Figure 3. Effect of biochar and sub-bituminous on CEC and base cations

Table 2.Pearson correlation of chemical properties

Soil properties	pH H_2O	Avail P	Org C	Tot N	CEC	K	Ca	Mg	Al	C:N
pH H_2O	1	0.476	0.640	0.639	0.608	0.636	0.648	0.513	-0.725	0.626
Avail P		1	0.421	0.682	0.592	0.961**	0.936**	0.832*	-0.920**	0.470
Org C			1	0.919**	0.812*	0.493	0.587	0.162	-0.595	0.993**
Tot N				1	0.947**	0.706	0.730	0.392	-.0733	0.912*
CEC					1	0.619	0.576	0.347	-0.586	0.775
K						1	0.972**	0.911*	-0.954**	0.545
Ca							1	0.832*	-0.987**	0.647
Mg								1	-0.795	0.227
Al									1	-
C:N										1

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

3.2 The effects of sub-bituminous and biochar on height, number of leaves, and branches of Coffee Plants

Figure 4 shows that the growth of coffee height reaches a peak from the 1st to 8th weeks after planting, and constantly increases until the 28th week, since in the 1st to 8th weeks, the plant experiences a rapid growth phase on its shoots and branches. However, in the 8th week and other next weeks, the plants entered a more dominant leaf-growing phase (Figure 5). In this condition, the nutrient uptake is no longer only for its shoots and branches, but also to spread over plant leaves.

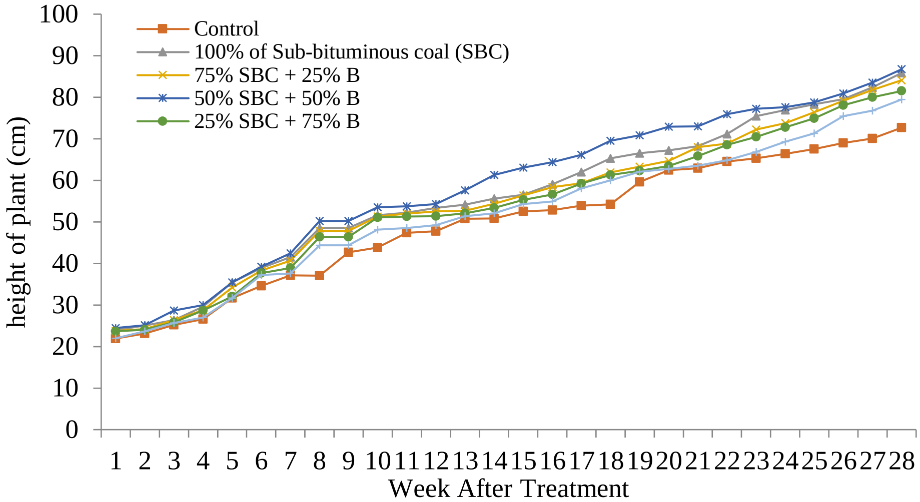


Figure 4. Effect of sub-bituminous and biochar on coffee height in ultisols

In the last week of observation, height, branches, and number of leaves of not really significant (Figure 4, Figure 5, and Figure 6). However, the treatment of 50% sub-bituminous + 50% bamboo biochar shows the best plant height. This effect was also consistent with the number of branches and leaves of coffee plants. These indicate that the application of 50% sub-bituminous + 50% bamboo biochar can be combined well in increasing soil fertility and plant growth. We can identify that there were five (5) significant improvements in soil properties in the treatment, namely P, CEC, K, Ca, and Mg (Table 1) which are important for the growth of coffee [30,31]. Plant height growth can also be useful because it can prevent the growth of dense branches and leaves [32].

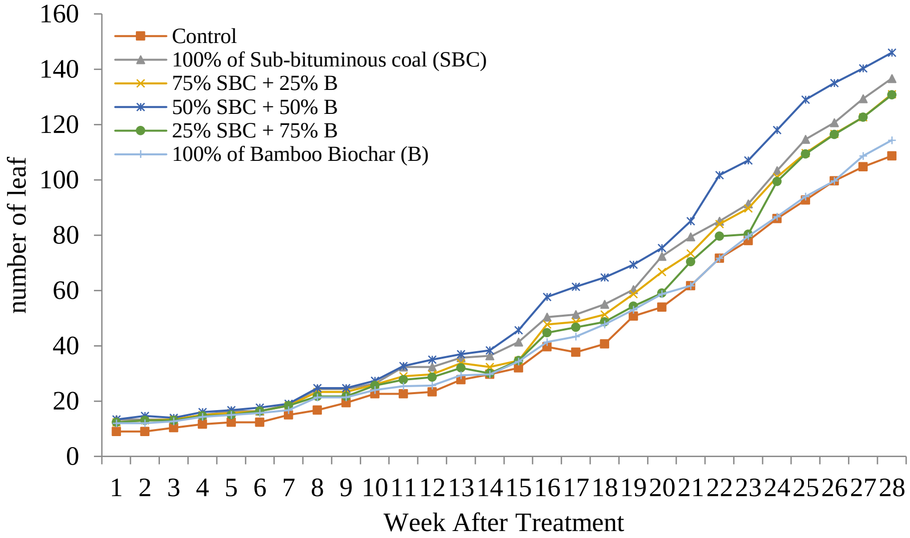


Figure 5. Effect of sub-bituminous and biochar on the number of leaves of coffee plants

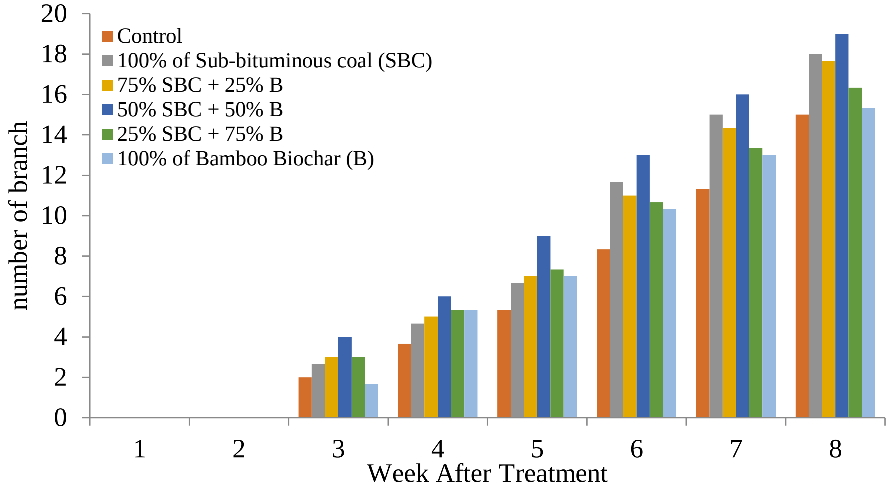


Figure 6. Effect of sub-bituminous and biochar on the number of branches of coffee plants

4. Conclusion

From the results of this study it can be concluded that biochar bamboo can be combined well with sub-bituminous in improving ultisol's fertility. The formulation of 50% sub-bituminous + 50% bamboo biochar is recommended as amendment in increasing soil fertility of ultisols (available P, CEC, K^{+}, Ca^{2+} and Mg^{2+}) and increasing the plant height, the number of branches, and the leaves of the arabica coffee in the seedling stage.

References

[1] Subagyo, H., N. Suharta, dan A.B. Siswanto. 2004. *Tanah-tanah Pertanian di Indonesia*. Dalam A. Adimihardja, L.I. Amien, F. Agus, D. Djaenudin (Ed.). *Sumberdaya Lahan Indonesia dan Pengelolaannya*. Pusat Penelitian dan Pengembangan Tanah dan Agroklimat, Bogor. Hlm 21−66.

[2] Statistics Indonesia. 2020. Production of plantation crops and plantation area by province. https://www.bps.go.id/subject/54/perkebunan.html#subjekViewTab3

[3] INBAR - International Network for Bamboo and Rattan. 2005.. Global Forest Resources Assessment. Update 2005. Indonesia Cauntry Report on Bamboo Resources. Forest Resources Assessment Working Paper (Bamboo) Food and Agriculture Organization of The United Nations, Forestry Departement, and International Network for Bamboo and Rattan. Jakarta

[4] Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: A review. Plant and Soil, 337(1), 1–18. https://doi.org/10.1007/s11104-010-0464-5

[5] Uchimiya, M., Chang S., Klasson KT. 2011. Screening biochars for heavy metal retention in soil: Role of oxygen functional groups. Journal of Hazardous Materials. 190 (1-3): 432-441. https://doi.org/10.1016/j.jhazmat.2011.03.063

[6] Novak, J. M., Lima, I., Xing, B., Gaskin, J. W., Steiner, C., Das, K. C., Ahmedna, M., Rehrah, D., Watts, D. W., Busscher, W. J., and, Harry, S. 2009. Characterization of designer biochar produced at different temperatures and their effects on a loamy sand, Annals Environ. Sci., 3, 195–206.

[7] Yuan, J.H., RK X, Zhang H. 2011. The forms of alkalis in the biochar produced from crop residues at different temperatures. Bioresour Technol 102:3488–3497

[8] Li, H., Dong X., da Silva E.B., de Oliveira L.M., Chen, Y., Ma, L.Q. 2017. Mechanisms of metal sorption by biochars: Biochar characteristics and modifications. Chemosphere. 178: 466-478

[9] Trupiano, D., Cocozza, C., Baronti, S., Amendola, C., Vaccari, FP., Lustrato, G., Lonardo, S.D., Fantasma, F., Tognetti, R., and Scippa, GS. The Effects of Biochar and Its Combination with

Compost on Lettuce (Lactuca sativa L.) Growth, Soil Properties, and Soil Microbial Activity and Abundance. International Journal of Agronomy. 12 p. https://doi.org/10.1155/2017/3158207
[10] Ramola, S and Srivaastava, R.K. 2013. Effect of biochar application in combination with domestic wastewater on biomass yield of bioenergy plantations. International Journal of Energy Sector Management. 7 (3): 355-363. doi: 10.1108/IJESM-03-2013-0005
[11] Kocaturk, N.P., Zwart Kor., Bruun S., Brussaard L., and Jensen, L.S. 2016. Does the combination of biochar and clinoptilolite enhance nutrient recovery from the liquid fraction of biogas digestate?, Environmental Technology. http://dx.doi.org/10.1080/09593330.2016.1226959
[12] Rezki, D. 2007. *Ekstraksi Bahan Humat dari Batubara (Sub-bituminus) dengan Menggunakan 10 Jenis Pelarut*. [skripsi]. Fakultas pertanian. Universitas Andalas. Padang. 63 hal.
[13] Tan, K. H. 2003. Humic Matter in soil and the environtment. Principles and Controversies. Marcel Dekker, Inc. New York. 386 p.
[14] ICCRI - Indonesian coffee and cocoa research institute.2006. *Pedoman Teknis Tanaman Kopi*. Jember 70 budidaya dan pasca panen kopi.96 hal
[15] Thomas GW. 1982. Exchangable cation. In Pages AL et al. (Eds). Method of Soil Analysis (Part 2) – Chemical and Microbial properties (2nd Edition). American Society of Agronomy and Soil Science Society of America. 159 – 179
[16] Nelson DW & Sommers LE. 1982. Total carbon, organic carbon, and organic matter. In Pages AL et al. (Eds). Method of Soil Analysis (Part 2) – Chemical and Microbial properties (2nd Edition). American Society of Agronomy and Soil Science Society of America. 539 – 579
[17] Cornellissen G., Martinsen V., Shitumbanuma, V., Alling V., Breeveld G., Rutherford DW., Sparrevik, M., Hale, S.E., Obia, A., Mulder J. 2013. Biochar Effect on Maize Yield and Soil Characteristics in Five Conservation Farming Sites in Zambia. Agronomy (3): 256-274. doi:10.3390/agronomy3020256
[18] Joseph, S.D., Camps-Arbestain, M., Lin, Y., Munroe, P., Chia, C.H., Hook, J., van Zwieten L., Kimber, S., Cowie A., Singh BP., Lehmann, J, Foid, 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
[19] Herviyanti., Ahmad, F., Sofyani, R., Darmawan, Gusnidar, dan Saidi A. 2012. Pengaruh Pemberian Bahan Humat dari Ekstrak Batubara Muda (Subbituminus) dan Pupuk P terhadap Sifat Kimia Ultisol serta Produksi Tanaman Jagung (Zea mays L.). J. Solum (9):15-24
[20] Han, L., Qian, L., Liu, R., Chen, M., Yan, J., Hu, Q. 2017. Lead adsorption by biochar under the elevated competition of cadmium and aluminum. Nature (7): 2264. DOI:10.1038/s41598-017-02353-4
[21] Qian, T., Wang, Y., Fan, T., Fang, G. & Zhou, D. 2016. A new insight into the immobilization mechanism of Zn on biochar: The role of anions dissolved from ash. Sci. Rep (6): 33630. doi:10.1038/srep33630
[22] Xu, G., Wei, LL., Sun, J.N., Shao, H.B., Chang S.X. 2013. What is more important for enhancing nutrient bioavailability with biochar application into a sandy soil: Direct or indirect mechanism? Ecological Engineering. 2013 (53): 119–124
[23] Sasmita, K.D., Anas I., Anwar S., Yahya S., Djajakirana G. 2017. Application of Biochar and Organic Fertilizer on Acid Soil as Growing Medium for Cacao (Theobroma cacao L.) Seedlings. International Journal of Sciences: Basic and Applied Research (36): 261-273.
[24] Herviyanti., Prasetyo TB., Juniarti, and Rezki D. 2017. Activation Unproductive Coal Powder with Urea to Improve Chemical Properties of Ultisols. International Journal on Advanced Science, Engineering and Information Technology (7): 957-963.
[25] Herviyanti., Prasetyo TB., Juniarti., Prima S., and Wahyuni., S. 2018. The Role of Sub-bituminous Coal Powder with Sodium Hydroxide (NaOH) to Improve Chemical Properties of Ultisols. International Journal on Advanced Science Engineering Information Technology (8): 2052-2058

[26] Nowicki, P., Pietrzak R. 2011. Effect of ammoxidation of activated carbons obtained from sub-bituminous coal on their NO2 sorption capacity under dry conditions. Chemical Engineering Journal (166): 1039–1043. doi:10.1016/j.cej.2010.11.101
[27] Sombroek, W. G., Nachtergaele, F. O., Hebel, A. 1993. Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. Ambio (22): 417–426.
[28] Kuhlbusch, T. A. J., Crutzen, P. J. 1995. Toward a global estimate of black carbon in residues of vegetation fires representing a sink of atmospheric CO2 and a source of O2. Global Biogeochem. Cycl (9): 491–501.
[29] Verheijen, F., Jeffery, S., Bastos, A.C., van der Velde, M., Diafas, I. 2010. Biochar Application to Soils. A Critical Scientific Review of Effects on Soil Properties. Processes and Functions, JRC Scientifical and Technical Reports. (http://81.47.175.201/ET2050_library/docs/tech/environment/Biochar.pdf)
[30] Zhang, Zx., Cai Z.Q., Liu, Gz., Wang H., Huang., And Cai, C.T. 2017. Effects of Fertilization on the Growth, Photosynthesis, and Biomass Accumulation in Juvenile Plants of three Coffee (Coffea Arabica L.) Cultivars. Photosynthetica 55 (1): 134-143.
[31] Da Matta F.M., do Amaral J.A.T., Rena A.B. 1999. Growth periodicity in trees of Coffea arabica L. in relation to nitrogen supply and nitrate reductase activity. Field Crop Res. 60: 223-229.
[32] Wang, X.S., Liu J., Wu, R.R. et al. 2014. Growth and yield of five coffee varieties in dry and hot valley of Lujiangba, Baoshan. Chin. J. Trop. Agr. 34: 4-8.