Biochar Application on Spodosols Soils Promotes Higher Plant Growth and Survival Rate

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ABSTRACT
Interests in biochar applications for improving soil properties and fertility are increasing worldwide, and numerous production techniques, raw materials, and application options are now available. This research aimed to investigate the effects of biochar application on growth rate (height, stem diameter, leaf number, and survival) performance of *Anthocephalus cadamba* seedling planted on degraded Spodosols on bioassay trial in the nursery. Bioassay trial was carried out in Forestry Faculty of Mulawarman University, Samarinda, Indonesia. It followed Completely Randomized Design (CRD) applying six levels of treatments, i.e., 0, 2, 5, 10, 25, and 100%v of biochar, and three replications. The 100%v biochar treatment was aimed at investigating the potential of applying biochar for primary media in raising seedlings in the nursery as the replacement of the conventional media. Of those six levels of treatments, the 10%v biochar treatment gave the best height growth at $p = 0.05$, and 25%v showed the best stem diameter growth but not statistically significant. Even though it was not statistically significant, low-level biochar application (up to 5%v) on spodosols soils improved plant survival. Based on the results of this preliminary on the effect of biochar application on plant growth and survival on spodosols soils, it is concluded that: (1) the application of biochar on such soils might be promising and (2) the development of biochar as main media for raising seedling in nursery might also be beneficial.

Keywords: *Biochar, Spodosols, Growth rate, Plantation media, Anthocephalus cadamba*

1. INTRODUCTION

The applications' long-term multi-benefits drive the tremendous worldwide increase of interest in biochar application in the last few decades. Regardless the debate on the magnitude, uncertainties and residence time effects, biochar application promotes the improvement of water and nutrient retention [1,2,3,4]; soil microbial biomass, activities and structures [5,6]; fertilizer and nutrient use efficiency [7,8]; soil physical properties [9,10]; immobilization of toxic substances in soils [11,12]; plant growth and productivity [13,14,15,16,17]; plant drought and salinity resistance [18,19,20,21,22]; plant toxicity resistance [11,12,23,24]; plant disease resistance [25,26]; nitrous oxide and methane emission reduction [27,28,29]; and soil carbon pool [30,31,32].

At the COP21 meeting in Paris, 103 countries have set mitigation, and adaptation targets in agriculture and other land uses, including forests and degraded land [33], leading to the '4 per 1000 Initiative'. This initiative sets an annual global increase of SOC stock at the rate of 0.4% of global anthropogenic emission in all land uses to mitigate the buildup of atmospheric CO_2.

The role of land carbon management needs to be reexamined. Namely, soil organic carbon (SOC) sequestration, afforestation, and reforestation, including tree planting through agroforestry, are the only land-based harmful emissions (i.e., removing CO_2 from the atmosphere) that are readily available at low cost [34]. Soils also carry a significant potential for carbon sequestration, primarily through restoration measures on degraded soils [35]. About 90% of the total technical mitigation potential in agriculture (excluding bioenergy and improved energy use) is based on SOC sequestration options [36,37].

Carbon sequestrations in agricultural soils are essential for atmospheric carbon dioxide mitigation and soil fertility enhancement [4,32]. However, traditional soil organic carbon (SOC) enrichment practices involving incorporation of biomass residues and green manures not only result in rapid mineralization and release of CO2 to the atmosphere [38,39,40,41] but also subject to the enhancement of methane and nitrous oxide emission [42] contributing to higher global warming potential. In contrast to traditional organic materials, biochar is a highly carbonized material produced by pyrolysis that consists of many aromatic compounds resistant to biological degradation [43]. It may stay in soils for hundreds to thousands of years [44,45]. Therefore, biochar application is a promising alternative to sequester more C in soils than traditional practices and is rated as the best geo-engineering option for carbon sequestration [46]. Large-scale biochar applications will increase the soil carbon pool contributing to climate change mitigation [47].

Over several decades, studies have demonstrated that improved land use and management can help to sequester organic C in soil and reduce greenhouse gas (GHG) emissions [34,48,49]. This opportunity was the motivation behind the "4 pour 1000" initiative, launched at the COP21 meeting in Paris, aiming to increase global soil organic C stocks by four parts per 1000 (or 0.4%) per year as compensation for global GHG emissions from anthropogenic sources. At a world land area of 149 million km^2, an estimated SOC on average would come to 161 tonnes per hectare or an average sequestration rate to offset emissions at 0.6 tonnes of C per hectare per year. SOC sequestration rates across the world may come to an annual rate of 0.2 to 0.5 tonnes C per hectare [50].

Biochar application to soils leads to dual benefits of long-term carbon sequestration and potentially positive soil amendment [51,52,53]. In particular, the ability of biochar to act as a feasible climate change mitigation technology, implementable at a globally significant scale, is recognized [54], with the potential to sequester the equivalent of up to 12% of anthropogenic greenhouse gas (GHG) emissions [55] in ecologically and economically sustainable systems.

The application of biochar on degraded weathered soils in the tropics would benefit SOC sequestration and crop production. This study was devoted to the evaluation of the possibility of biochar application on Spodosols in East Kalimantan.

2. METHODS

The leaves of *E. pellita* were collected from PT Surya Hutani Jaya, Sebulu, Kutai, East Kalimantan, Indonesia. The sample was prepared to air-dried for 24 h maintaining the integrity of the specifications.

Growth media preparation, including arrangement and tests, was carried out at the Soil Science Laboratory and the Soil and Water Conservation Laboratory, Faculty of Forestry, Mulawarman University, Samarinda. Bioassay test for *Anthocephalus cadamba* seedlings was carried out at the nursery of the Faculty of Forestry, Mulawarman University.

Spodosols soil used for this research's growth media was collected from nearby degraded Spodosols soil while biochar used was produced based on retort biochar production method [13]. The raw material for the biochar production is derived from adjacent plantation waste of *Vitex pinnata*.

Biochar was ground to powder to pass a 2-mm-sieve before mixing with soils. Biochar application in this research was prepared to comply with the Completely Randomized Design procedure. Six level of biochar application for growth media were arranged, those are: 0%v, 2%v, 5%, 10%v, 25%v and 100%v. Treatment was replicated three times, each consist of 20 seedlings; thus, this research involved 360 seedlings of *Anthocephalus cadamba*. Low-level biochar treatment was established to evaluate biochar treatment's importance in promoting plant growth on degraded Spodosols soils. In contrast, high-level biochar treatment was established to evaluate the possibility of using biochar as major media for plant growth in nurseries.

The effect of biochar treatment on the growth of *Anthocephalus cadamba* seedlings was assessed by incrementing seedlings' height and diameter. The size of seedlings was defined weekly, and the diameter was determined at the end of the research period, three months after replanting. However, the survival of seedlings was also calculated weekly.

Data collected in this research were tested and adjusted to normal distribution before analysis of variance and mean different test with the help of SPSS software.

3. RESULT AND DISCUSSIONS

The importance of biochar on plant survival is mostly driven by plant tolerant on salinity [18, 20,21], resistant on diseases [26,25], drought-resistant [18,19,56,57] and heavy metals and toxic elements resistance [11,12,23,23]. The survival of *Anthocephalus cadamba* seedlings was calculated as the ratio of the number of life seedlings to the number of those at the start of the study. Table 1 shows the survival of seedlings at the end of the study.

Table 1. Survival of seedlings at the end of the study

Treatment	Biochar (%v)	Survival (%)
A0	0,00	96,67
A1	2,00	98,33
A2	5,00	98,33
A3	10,00	93,33
A4	25,00	93,33
A5	100,00	91,67

At the full range of biochar application levels, ranging from 0% to 100%, there is no significant effect of biochar application on the survival rate of seedlings studied. Nevertheless, applying low-level biochar promoted higher survival of seedlings than control, 0% biochar application, but not high-level biochar. However, all treatments gave a high survival rate, more than 90%, including 100% biochar treatment. Biochar application on growth media in the nursery also showed high survival for Dipterocarps seedling [13,58]. This demonstrated that biochar's use as the primary media for raising seedlings in the nursery is of interest.

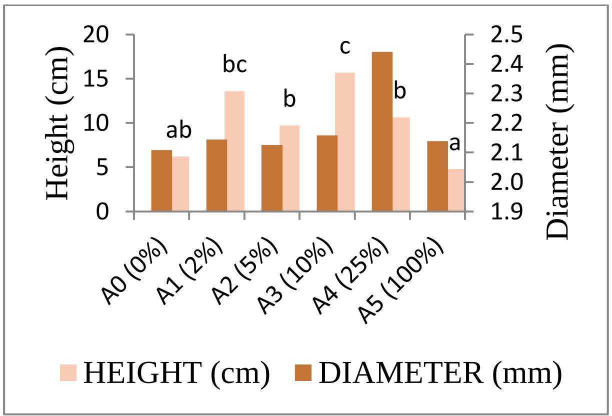

Figure 1 Diameter and height of seedlings at the end of the study

The average plant height increased in line with the plant's age till the end of the observation period (3 months after replanting). The difference in the size of plants among biochar application levels also increased with age. At the end of the observation period, three months after replanting, excluding the height of seedlings planted at growth media of 100% biochar treatment, the average height of plants in all media receiving biochar treatment was higher than that without biochar (Figure 1), application of 10%v biochar gave highest seedlings height, $p < 0.01$. Biochar modifies the environmental conditions of the growing media through the improvement of aeration, water availability [59][60][61], soil reactions, microorganism activity in the soil, and availability of plant nutrients [62][63] to facilitate the optimal utilization of the resources of plant roots environment which in turn will increase plant growth. However, at higher biochar application (25%v and 100%v), the height growth rate of *Anthocephalus cadamba* seedlings decreased, which may attribute to the nutrient immobilization by microorganism consuming volatile matter in biochar [64,65].

The diameter growth rate of *A. cadamba* seedlings showed a similar manner to that of height growth rate, but less pronounce and higher preference to the biochar application level. At the end of the observation period, three months after replanting, the average diameter of plants in all media receiving biochar treatment was higher than that without biochar (Figure 1). The application of 25%v biochar gave the most increased seedlings diameter but not statistically different. The growth rate of seedling diameter showed a positive response to a wide range of biochar application levels. Even though the diameter growth rate response of *A. cadamba* seedlings to the application of 100% biochar treatment was less pronounced, the growth rate was still higher than that of control. Here again, using biochar for significant plant growth media in raising seedlings in the nursery is promising.

4. CONCLUSIONS

Application of biochar on such degraded, strongly weathered soils might benefit long-term carbon sequestration and soil amendment. Juveniles gave a positive response to a wide range of biochar applications in such soils. This suggests that biochar development as the primary media for raising seedlings in the nursery might also be beneficial.

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REFERENCES

[1] K.Y. Chan, L.V. Zwieten, I. Meszaros, A. Downie, S. Joseph, Agronomic values of green waste biochar as a soil amendment, Aust J Soil Res 45 (2007) 629–634.

[2] C. Steiner, W.G. Teixeira, J. Lehmann, T. Nehls, J.L.V. Macêdo, W.E.H. Blum, W. Zech, Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil, Plant Soil, 29 (2007) 275-290. DOI: 10.1007/s11104-007-9193-9.

[3] B. Liang, J. Lehmann, D. Solomon, J. Kinyangi, J. Grossman, B. O'Neill, J.O. Skjemstad, J. Thies, F.J. Luizão, J. Petersen, E.G. Neves, Black carbon increases cation exchange capacity in soils, Soil Sci. Soc. Am. J., 70 (2006) 1719-1730. DOI: 10.2136/sssaj2005.0383.

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

[5] J. Lehmann, M.C. Rillig, J. Thies, C.A. Masiello, W.C. Hockaday, D. Crowley, Biochar effects on soil biota: A review, Soil Biol. Biochem., 43 (2011) 1812–1836. DOI: 10.1016/j.soilbio.2011.04.022.

[6] J. Thies, M.C. Rillig, Characteristics of biochar: Biological properties, In: J. Lehmann and S. Joseph, editors, biochar for environmental management: Science and technology, Earthscan, London, 2009, pp. 85–105.

[7] H. Schulz, B. Glaser, Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment, Journal of Plant Nutrition and Soil Science 175 (2012) 410–422. DOI: https://doi.org/10.1002/jpln.201100143

[8] T. DeLuca, M. MacKenzie, M. Gundale, Biochar effects on soil nutrient transformations. In J. Lehmann, S. Joseph (Eds.), biochar for environmental management: Science and technology, 2009, pp. 251–270. London, UK: Earthscan. DOI: https://doi.org/10.4324/9781849770552

[9] A. Mukherjee, R. Lal, Biochar impacts on soil physical properties and greenhouse gas emissions, Agronomy 3 (2013) 313–339. DOI: https://doi.org/10.3390/agronomy3020313

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

[11] M. Rizwan, S. Ali, M.F. Qayyum, M. Ibrahim, M. Zia-ur-Rehman, et al., Mechanisms of biochar-mediated alleviation of toxicity of trace elements in plants: a critical review, Environ Sci Pollut Res 23 (2016) 2230–2248. DOI: 10.1007/s11356-015-5697-7.

[12] F. Rees, C. Germain, T. Sterckeman, J-L. Morel, Plant growth and metal uptake by a non-hyperaccumulating species (*Lolium perenne*) and a Cd-Zn hyperaccumulator (*Noccaea caerulescens*) in contaminated soils amended with biochar, 2015.

[13] S. Syahrinudin, A. Wijaya, T. Butarbutar, W. Hartati, I. Ibrahim, M. Sipayung, Biochar produced by retort closed drum kiln promotes higher plant growth rate (Biochar yang diproduksi dengan tungku drum tertutup retort memberikan pertumbuhan tanaman yang lebih tinggi), ULIN: Jurnal Hutan Tropis, 2(1) (2018). DOI: https://doi.org/10.32522/u-jht.v2i1.1291

[14] A. Liu, D. Tian, Y. Xiang, H. Mo, Biochar improved growth of an important medicinal plant (*Salvia miltiorrhiza* Bunge) and inhibited its cadmium uptake, J Plant Biol Soil Health 3(2) (2016) 1-6.

[15] K. William, R.A. Qureshi, Evaluation of biochar as fertilizer for the growth of some seasonal vegetables, J. Bioresource Manage. 2(1) (2015) 41-46.

[16] S. Carter, S. Shackley, S. Sohi, T.B. Suy, S. Haefele, The impact of biochar application on soil properties and plant growth of pot grown lettuce (*Lactuca sativa*) and cabbage (*Brassica chinensis*), Agronomy 2013, 3(2) (2013) 404-418, DOI: 10.3390/agronomy3020404.

[17] G. Cornelissen, V. Martinsen, Shitumbanuma, V. Alling, G.D. Breedveld, D.W. Rutherford, et al., Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia, Agronomy 3 (2013) 256-274. DOI: 10.3390/agronomy3020256.

[18] S. Ali, M. Rizwan, M.K. Qayyum, Y.S. Ok, M. Ibrahim, et al., Biochar soil amendment on alleviation of drought and salt stress in plants: a critical review, Environ Sci Pollut Res 24 (2017) 12700–12712. DOI: 10.1007/s11356-017-8904-x.

[19] D. Egamberdieva, M. Reckling, S. Wirth, Biochar-based Bradyrhizobium inoculum improves growth of lupin (*Lupinus angustifolius* L.) under drought stress, Eur J Soil Biol 78 (2017) 38–42.

[20] S. Farhangi-Abriz, S. Torabian, Biochar Increased Plant Growth-Promoting Hormones and Helped to Alleviates Salt Stress in Common Bean Seedlings, J Plant Growth Regul. (2017) DOI: 10.1007/s00344-017-9756-9.

[21] H.S. Kim, K.R. Kim, J.E. Yang, Y.S. Ok, G. Owens, T. Nehls, G. Wessolek, K.H. Kim, Effect of biochar on reclaimed tidal land soil properties and maize (*Zea mays* L.) response, Chemosphere 142 (2016) 153–159.

[22] S.S. Akhtar, M.N. Andersen, F. Liu, Biochar mitigates salinity stress in potato, J Agron Crop Sci 201 (2015) 368–378.

[23] J. Gartler, B. Robinson, K. Burton, L. Clucas, Carbonaceous soil amendments to biofortify crop plants with zinc, Sci Total Environ 465 (2013) 308–313. DOI: 10.1016/j.scitotenv.2012.10.027.

[24] R.L. Zheng, C. Cai, J.H. Liang, Q. Huang, Z. Chen, Y.Z. Huang, G.X. Sun, The effects of biochars from rice residue on the formation of iron plaque and the accumulation of Cd, Zn, Pb, As in rice (*Oryza sativa* L.) seedlings, Chemosphere 89 (2012) 856–862. DOI: 10.1016/j.chemosphere.2012.05.008.

[25] W. Huang, H. Ji, G. Gheysen, J. Debode, T. Kyndt, Biochar-amended potting medium reduces the susceptibility of rice to root-knot nematode infections, BMC Plant Biology 15 (2015) 267-281. DOI: 10.1186/s12870-015-0654-7.

[26] Z.H. Mehari, Y. Elad, D. Rav-David, E.R. Graber, Y.M. Harel, Induced systemic resistance in tomato (*Solanum lycopersicum*) against Botrytis cinerea by biochar amendment involves jasmonic acid signalling, Plant Soil 395 (2015) 31–44. DOI: 10.1007/s11104-015-2445-1.

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

[28] Yanai, Yosuke, K. Toyota, M. Okazaki, Effects of charcoal addition on N2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments, Soil Science & Plant Nutrition 53(2) (2007) 181-188.

[29] M. Rondon, J.A. Ramirez, J. Lehmann, Charcoal additions reduce net emissions of greenhouse gases to the atmosphere, Paper read at Proceedings of the 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration, March 21-24 2005, at Baltimore, USA, 2005.

[30] W.W. Lu, W.X. Ding, J.H. Zhang, Y. Li, J.F. Luo, N. Bolan, Z.B. Xie, Biochar suppressed the decomposition of organic carbon in a cultivated sandy loam soil: A negative priming effect, Soil Biol. Biochem., 76 (2014) 12-21, DOI: 10.1016/j.soilbio.2014.04.029

[31] F. Luo, J. Song, W.X. Xia, M.G. Dong, M.F. Chen, P. Soudek, Characterization of contaminants and evaluation of the suitability for land application of maize and sludge biochars, Environ. Sci. Pollut. Res. Int., 21 (2014) 8707-8717. DOI: 10.1007/s11356-014-2797-8

[32] J. Lehmann, A handful of Carbon, Nature 477 (2007) 143–144. DOI: 10.1038/447143a.

[33] M. Richards, T.B. Bruun, B.M. Campbell, G. Le, S. Huyer, V. Kuntze, M. Stn, Mb. Oldvig, I. Vasileiou, How Countries Plan to Address Agricultural Adaptation and Mitigation: An Analysis of Intended Nationally Determined Contributions, (CCAFS dataset), 2016.

[34] P. Smith, D. Martino, Z. Cai, D. Gwary, H. Janzen, et al, Greenhousegas mitigation inagriculture, Philos. Trans. R. Soc. Lond. BBiol. Sci. 363 (2008) 789–813. DOI: http://dx.doi.org/10.1098/rstb.2007.2184.

[35] R. Lal, Managing soils and ecosystems for mitigating anthropogenic carbon emissions and advancing global food security, Bioscience 60 (2010) 708–721. DOI: http://dx.doi.org/10.1525/bio.2010.60.9.8.

[36] P. Smith, S.J. Davis, F. Creutzig, S. Fuss, J. Minx, et al, Biophysical and economic limits to negative CO2 emissions, Nat. Clim. Change 6 (2016) 42–50. DOI: http://dx.doi.org/10.1038/nclimate2870.

[37] K. Paustian, J. Lehmann, S. Ogle, D. Reay, G.P. Robertson, P. Smith, Climatesmart soils, Nature 532 (2016) 49–57. DOI: http://dx.doi.org/10.1038/nature17174.

[38] E.W. Bruun, P. Ambus, H. Egsgaard, H. Hauggaard - Nielsen, Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics, Soil Biology and Biochemistry 46 (2012) 73-79. DOI: https://doi.org/10.1016/j.soilbio.2011.11.019.

[39] Baker, M. John, E. Tyson, Ochsner, T. Rodney, Venterea, J. Timothy, Griffis, Tillage and soil carbon sequestration - What do we really know?, Agriculture Ecosystems & Environment 11 (2007) 1-5.

[40] J. Lehmann, J. Gaunt, M. Rondon, Bio-char sequestration in terrestrial ecosystems: A review, Mitig. Adapt. Strategies Glob. Change 11 (2006) 395–419. DOI: 10.1007/s11027-005-9006-5.

[41] D.R. Sauerbeck, CO2 emissions and C sequestration by agriculture - perspecives and limitations, Nutrient Cycling in Agroecosystems 60 (2001) 253-266.

[42] A.V. Palumbo, J.E. Amonette, L.S. Fisher, S.D. Wullshleger, W.L. Daniels, Prospects for enhancing carbon sequestration and reclamation of degraded lands with fossil-fuel combustion by-products, Advances in Environmental Research 8 (2004) 425-438.

[43] J.A. Baldock, R.J. Smernik, Chemical composition and bioavailability of thermally altered Pinus resinosa (red pine) wood, Organic Geochemistry 33 (2002) 1093–1109.

[44] Kuzyakov, Yakov, I. Subbotina, H. Chen, I. Bogomolova, X. Xu, Black carbon decomposition and incorportaion into soil microbial biomass estimated by 14C labelling, Soil Biology & Biochemistry 41 (2009) 210-219.

[45] R. Lal, Global Potential of Soil Carbon Sequestration to Mitigate the Greenhouse Effect, Critical Reviews in Plant Sciences 22(2) (2003) 151-184.

[46] T.M. Lenton, N.E. Vaughan, The radiative forcing potential of different climate geo-engineering options, Atmos. Chem. Phys. Discuss 9 (2009) 2559-2608.

[47] N. Ameloot, S. De Neve, K. Jegajeevagan, G. Yildiz, D. Buchan, Y.N. Funkuin, S. Sleutel, Short - term CO2 and N2O emissions and microbial properties of biochar amended sandy - loam soil, Soil Biology and Biochemistry, 57 (2013) 401 - 410. DOI: https://doi.org/10.1016/j.soilbio.2012.10.025.

[48] S.M. Ogle, F.J. Breidt, K. Paustian, Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions, Biogeochem 72 (2005) 87–121.

[49] C. Poeplau, C. Vos, A. Don, Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content, SOIL, 3 (2017) 61–66. DOI: https://doi.org/10.5194/soil-3-61-2017.

[50] B. Minasny, B.P. Malone, A.B. McBratney, D.A. Angers, D. Arrouays, et al., Soil carbon 4 per mille, Geoderma 292 (2017) 59–86. http://dx.doi.org/10.1016/j.geoderma.2017.01.002.

[51] M. Dover, Anyone for char? Dark earth holds carbon storage hope, Inwood Magazine 77 (2007) 33–34.

[52] R. Lal, Challenges and opportunities in soil organic matter research, European Journal of Soil Science 60 (2009) 158–169.

[53] D.J. Tenenbaum, Biochar: Carbon mitigation from the ground up, Environmental Health Perspectives 117(2) (2009) A70-A73.

[54] M. Molina, D. Zaelke, K.M. Sarma, S.O. Andersen, V. Ramanathan, D. Kaniaru, Reducing abrupt climate change risk using the Montreal protocol and other regulatory actions to complement cuts in CO2 emissions, Proceedings of the National Academy of Sciences of the United States of America 106, 20616–20621, 2009.

[55] D. Woolf, J.E. Amonette, F.A. Street-Perrott, J. Lehmann, S. Joseph, Sustainable biochar to mitigate global climate change, Nature Commuications 1(5) (2010). DOI: 10.1038/ncomms1053.

[56] G. Haider, H-W. Koyro, F. Azam, D. Steffens, C. Müller, C. Kammann, Biochar but not humic acid product amendment affected maize yields via improving plant-soil moisture relations, Plant Soil 395 (2014) 141–157. DOI: 10.1007/s11104-014-2294-3.

[57] C.I. Kammann, S. Linsel, J.W. Gößling, H-W. Koyro, Influence of biochar on drought tolerance of Chenopodium quinoa Willd and on soil–plant relations, Plant Soil 345 (2011) 195–210. DOI: 10.1007/s11104-011-0771-5.

[58] Marjenah, Kiswanto, S. Purwanti, F.P.M. Sofyan, The effect of biochar, cocopeat and saw dust compost on the growth of two dipterocarps seedlings, Nusantara Bioscience 8(1) (2016) 39-44.

[59] E.P.A. Pratiwi, Y. Shinogi, Rice husk biochar application to paddy soil and its effects on soil physical properties, plant growth, and methane emission, Paddy Water Environ 14 (2016) 521–532. DOI: 10.1007/s10333-015-0521-z.

[60] S. Abel, A. Peters, S. Trinks, H. Schonsky, M. Facklam, G. Wessolek, Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil, Geoderma 202 (2013) 183–191.

[61] H. Herath, M. Camps-Arbestain, M. Hedley, Effect of biochar on soil physical properties in two contrasting soils: an Alfisol and an Andisol, Geoderma 209–210 (2013) 188–197.

[62] R.S. Dharmakeerthi, J.A.S. Chandrasiri, V.U. Edirimanne, effect of rubber wood biochar on nutrition and growth of nursery plants of Hevea brasiliensis established in an Ultisol, SpringerPlus, 1:84, 2012.

[63] J. Major, M. Rondon, D. Molina, S.J. Riha, J. Lehmann, Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol, Plant Soil 333 (2010) 117–128.

[64] B.M.D. Kanouo, S.E. Allaire, A.D. Munson, Quality of Biochars Made from Eucalyptus Tree Bark and Corncob Using a Pilot-Scale Retort Kil, Waste Biomass Valor, 2017. DOI: 10.1007/s12649-017-9884-2.

[65] D. Sun, J. Meng, H. Liang, E. Yang, Y. Huang, et al, effect of volatile organic compounds absorbed to fresh biochar on survival of *Bacillus mucilaginosus* and structure of soil microbial communities, J Soils Sediments 15 (2015) 271–281. DOI: 10.1007/s11368-014-0996-z.