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Biochar enriched with organic fertilizer improves the survival and growth rate of *Anthocepalus cadamba* seedlings planted on degraded spodosols

SYAHRINUDIN[1,♥], WAHJUNI HARTATI[1], TRIOYONO SUDARMADJI[2], NURMAN KRISDIANTO[1], IBRAHIM[1]

[1]Laboratory of Silviculture Sciences, Faculty of Forestry, Universitas Mulawarman. Jl. Ki Hajar Dewantara, Gunung Kelua, Samarinda 75123, East Kalimantan, Indonesia. Tel.: +62-541-735089, Fax.: +62-541-735379, ♥email: syahri@ymail.com
[2]Laboratory of Soil and Water Conservation, and Climate, Faculty of Forestry, Universitas Mulawarman. Jl. Ki Hajar Dewantara, Gunung Kelua, Samarinda 75123, East Kalimantan, Indonesia

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Abstract. *Syahrinudin, Hartati W, Sudarmadji T, Krisdianto N, Ibrahim. 2019. Biochar enriched with organic fertilizer improves the survival and growth rate of* Anthocepalus cadamba *seedlings planted on degraded spodosols. Biodiversitas 20: 3741-3750.* The application of biochar for the improvement of soil properties and fertility has drawn enormous interest worldwide nowadays and numerous application options are now available. This research was aimed to evaluate the effects of the application of biochar and organic fertilizers on the survival and growth of *Anthocepalus cadamba* seedlings planted on degraded spodosols soil on bioassay trial in the nursery. Bioassay trial was carried out in the nursery of Faculty of Forestry, Mulawarman University, Samarinda, Indonesia, employing a 2-factors Completely Randomized Design (CRD) with factor 1 was the rate of biochar application (i.e. six levels of treatment: 0 (control), 2, 5, 10, 25 and 100%v of biochar), and factor 2 (enrichment of organic fertilizers, i.e. with enrichment and without enrichment), and each treatment combination had 3 replications. The results showed that biochar application alone improved height and diameter growth rate of *A. cadamba* seedlings by 253% and 116% of control treatment (without biochar), respectively. Enrichment of organic fertilizers gave further improvement in height and diameter growth rate of *A. cadamba* seedlings to 386% and 150% of control treatment (without biochar), respectively. Furthermore, biochar application improved survival and biomass growth rate of the seedlings. Enrichment of organic fertilizers into biochar improved not only seedling growth rate but also more interestingly the carrying capacity of spodosols to biochar application rate. We concluded that biochar application complemented with enrichment of organic fertilizers on spodosols is highly promising for the improvement of both soil carbon sequestration and plant growth performance.

Keywords: *Anthocepalus cadamba*, biochar, enrichment, growth, spodosol

INTRODUCTION

Climate change and global warming are among the most challenging environmental, economic and social issues worldwide. Carbon dioxide (CO_2), one of the most prominent anthropogenic-induced greenhouse gases, contributes to more than 51% of global warming. The level of atmospheric CO_2 has increased substantially, resulting in its content of about 760 Pg of carbon (C) as CO_2 (Schimel 1995; IPCC 2000). However, atmospheric C represents less than 30% of the C in terrestrial ecosystems. Vegetation contains nearly 500 Pg C, while soils contain another 2000 Pg C in the form of organic matter and detritus (Schimel 1995; IPCC 2000). Regardless the debate as to whether global forests are sources or sinks of greenhouse gases (Ravindranath et al. 1997; Lal and Singh 2000; Harmon 2001; Metting et al. 2001; Schimel et al. 2001; Pelley 2003), managed fast-growing forests may enhance C sequestration (Papadopol 2000; Metting et al. 2001; Lee et al. 2002; Ney et al. 2002).

There are great opportunities for mitigation of further increases in the atmospheric C pool in forestry (IPCC 2001). Forest-C sequestration has been identified as one of the most promising options to reduce the build-up of atmospheric CO_2 (Dixon et al. 1993; Sampson and Sedjo 1997; Marland and Schlamadinger 1999). Silvicultural strategies aiming at accelerating the stand growth are likely to increase the rate of C sequestration of the respective forests (Montagnin and Porras 1998; Chen et al. 2000; Lee et al. 2002; Budiharta et al. 2014). In respect of soil organic carbon (SOC) sequestration, afforestation and reforestation including tree planting through agroforestry, are the only land-based negative emissions (i.e. removing CO_2 from the atmosphere) which are readily available at low cost (Smith et al. 2016). Soils carry a significant potential for carbon sequestration, especially through restoration measures on degraded soils (Lal 2010) and biochar application may further increase SOC carrying capacity of the systems (Lehmann 2007; Lu et al. 2014; Luo et al. 2014).

Spodosols are common in the lowlands of the tropics (Roslan et al. 2010), forming from very sandy parent materials (Japony and Tan 1989); they are formed by the process of podzolization leading to the presence of spodic horizon, an illuvial layer with spodic materials (organic matter and/or oxides complexes) overlain by an albic horizon (Buurman and Jongmans 2004). Spodic materials are associated with vertical movement of organo-Al and/or Fe oxides complex (Wilson and Righi 2010). Soil grain dominated by quartz sand fraction (Roslan et al. 2010) coupled with low soil pH and CEC (Roslan et al. 2011) leads to low water holding capacity and low nutrient retention, resulting in limited land uses in spodosols. The occurrence of frequent flooding (Soil Survey Staff 1996) further limits utilization of these soils. Natural vegetation occupied such soils mostly heat forests (Davies and Becker 1996) and any disturbance to such forest leads to ecosystem and soil degradation (Becker 2006). Since there are many limitations on the cultivation of degraded spodosols, only limited number of species could be planted.

Anthocepalus cadamba-an early-succession species which grows best on deep, moist, alluvial sites, often in secondary forests along riverbanks and in the transitional zone between swampy, permanently flooded and periodically flooded areas (Soerianegara and Lemmens 1993)-is a promising species to cultivate on such soils. However, measures should be handled carefully to make the success of plantation in such soils. Therefore, the management of soil organic matter and plant nutrition are considered of utmost importance.

The world-wide tremendous increase of interest in biochar application in the last few decades is driven by the long-term multi-benefits given by the applications. Regardless the debate on the magnitude, uncertainties and residence time effects, biochar application promotes the improvement of water and nutrient retention (Glaser et al. 2002; Liang et al. 2006; Chan et al. 2007; Steiner et al. 2007); soil microbial biomass, activities and structures (Yu et al. 2018; Lehmann et al. 2011; Thies and Rillig 2009); fertilizer and nutrient use efficiency (DeLuca et al. 2009; Schulz and Glaser 2012); soil physical properties (Atkinson et al. 2010; Mukherjee and Lal 2013); immobilization of toxic substances in soils (Rees et al. 2015; Rizwan et al. 2015); plant growth and productivity (Carter et al. 2013; Cornelissen et al. 2013; William and Qureshi 2015; Liu et al. 2016; Syahrinudin et al. 2018); plant drought and salinity resistance (Akhtar et al. 2015; Kim et al. 2016; Ali et al. 2017; Egamberdieva et al. 2017; Farhangi-Abriz and Torabian 2017); plant toxicity resistance (Zheng et al. 2012; Gartler et al. 2013; Rees et al. 2015; Rizwan et al. 2015); plant disease resistance (Huang et al. 2015; Mehari et al. 2015); nitrous oxide and methane emission reduction (Rondon et al. 2005; Yanai et al. 2007; Spokas et al. 2009); and soil carbon pool (Lehmann 2007; Lu et al. 2014; Luo et al. 2014).

Application of biochar coupled with nutrient enrichment on degraded and heavily weathered soils in the tropics would be beneficial in terms of both SOC sequestration and crop production. Liquid organic fertilizer could improve the effectiveness of biochar application. Liquid organic fertilizers consist of essential plant nutrients and beneficial microorganisms, thus it could maintain soil sustainability and plant health (Dordas et al. 2007; Hou et al. 2017). Furthermore, compounds in liquid organic fertilizers, such as chitin, humic and fulvic acids, and other biopolymers, can be biostimulants to plants (Sharp 2013; Canellas et al. 2015). This study was devoted to evaluate the effects of the application of biochar and organic fertilizers on the survival and growth of *Anthocepalus cadamba* seedlings planted on spodosols soil at pot level.

MATERIALS AND METHODS

Study area and period

Growth media preparation, including arrangement and tests, was carried out at Soil Science Laboratory and Soil and Water Conservation Laboratory, Faculty of Forestry, Mulawarman University, Samarinda, Indonesia. Bioassay test for *Anthocepalus cadamba* seedlings was carried out at the nursery of the Faculty of Forestry, Mulawarman University. Research period was three months observation, after replanting the seedlings following the pre-observation works, biochar and liquid organic fertilizer production, soil media collection and nursery preparation for period of two months.

Procedure

Biochar production and media preparation

Spodosols soil used for the growth media of this research was collected from nearby degraded spodosols soil, 40 km northeast of Samarinda. These soils were very coarse in texture, very low in water holding capacity and nutrient retention (Prasetyo et al. 2006) while biochar used was produced based on retort biochar production method (Figure 1). Raw materials for the biochar production were wood of stem and branches of *Vitex pinnata* wastes derived from adjacent plantations. The raw materials were loaded into kiln drum, the kiln was then closed tightly to avoid air penetration, heated with external fuel, in this case liquid natural gas, till the production of gases from the heated materials. Thereafter, supply of external fuel was terminated, and further heating of the feedstock relied solely on the gases released by the materials. Once the produced gases were exhausted, the biochar production was completed. Peak production temperatures were about 400-500^{o}C for period of 30 minutes to one hour.

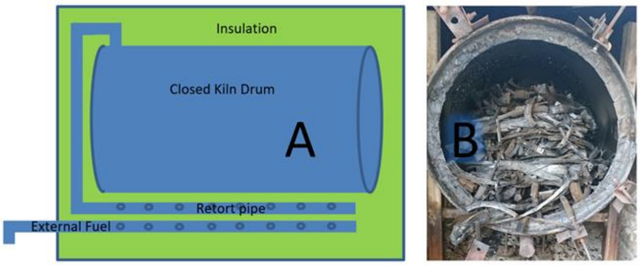

Figure 1. Schematic of closed drum retort kiln biochar production (A) and biochar produced with closed drum retort kiln (B)

Table 1. Selected properties of biochar with and without enrichment of nutrients

Properties	Without enrichment	With enrichment
pH H_2O	7.14	6.1
pH KCl	6.61	5.9
Nitrogen (%)	1.56	3.05
Available P (ppm)	82.11	105.02
Available K (ppm)	572.53	589.59

Biochar was ground to powder to pass a 2-mm-sieve prior to nutrient enrichment and mixing with soils. The nutrient enrichment of biochar was processed by inundating dry-fine biochar with liquid organic fertilizer for one hour prior to the mixing with soils. Liquid organic fertilizer used in this work was derived from anaerobic fermentation of vegetable wastes of local traditional market. The mixtures were then filled into polyethylene pots (10 cm diameter and 15 cm height), watered and kept overnight prior to the transplanting of seedlings. Selected properties of enriched-and without enrichment biochar are presented in Table 1.

Experimental design

Biochar application in this research was prepared to comply with a 2-factors (biochar application rate and nutrient enrichment) Completely Randomized Design procedure. Six levels of biochar application for growth media were arranged, those are 0%v, 2%v, 5%, 10%v, 25%v, and 100%v and two levels of nutrient enrichment, i.e.: liquid organic fertilizer enrichment and without enrichment. Treatment was replicated three times, each consisted of 20 seedlings, thus this research involved 720 seedlings of *A. cadamba*. Low levels of biochar treatment were established to evaluate the importance of biochar treatment in promoting plant growth on degraded spodosols soils, whereas high-level biochar treatment was established to evaluate the possibility of the using of biochar as major media for plant growth in nursery.

Data measurement and analysis

The effect of biochar treatment on the growth of *A. cadamba* seedlings was assessed by the increment of the height, diameter and biomass of seedlings. Height of seedlings was measured weekly and diameter and biomass of seedlings were measured at the end of the research period, 3 months after replanting. However, survival of seedlings was also recorded weekly.

Data collected in this research were tested and adjusted to normal distribution (Vasicek 1976) prior to analysis of variance (Fisher 1919) and mean different tests (Fisher 1935) with the help of SPSS software.

RESULTS AND DISCUSSION

Environmental factors, such as light, moisture, nutrients, density, and temperature (Chapin et al. 1987; Chen et al. 2015), and plant physiological factors, including carbohydrate reserves, hormone levels, and dormancy (George et al. 2008), work together in defining the growth and survival of seedlings. Biochar may alter environmental conditions of seedlings in such ways to give better conditions for the improvement of growth, survival, and quality of the seedlings (Dharmakeerthi et al. 2012; Haider et al. 2017). The survival of *A. cadamba* seedlings was calculated as ratio of number of life seedlings to the number of those at the start of the study. Table 2 shows the survival of seedlings at the end of the study. At the full range of biochar application level, ranging from 0% to 100%, nor biochar application rate neither treatment interaction gave significant effect on the survival rate of seedlings studied, nevertheless application of lower rate biochar promoted higher survival of seedlings as compared to that of control, 0% biochar application. In contrast to biochar application rate, nutrient enrichment gave significant effect on the survival rate of the seedlings studied, $p = 0.02$.

Nutrient enriched biochar promoted higher survival rate at all rates of biochar treatment (Table 2). These results suggest that the application of biochar soil amendment coupled with other materials such as fertilizer, sludge and composted organic wastes would further enhance the favorable conditions of plant growth media (Alburquerque et al. 2013; Schimmelpfennig et al. 2014; Marjenah et al. 2016). The addition of these materials into biochar application may further improve nutrient availability, i.e. nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients (Alburquerque et al. 2013; Gondek et al. 2018). Sludge and composted organic wastes may enhance not only nutrient availability but also biological structure and diversity of media (Luo et al. 2018). However, all treatments gave high survival rate, more than 90%, including that of 100% biochar treatment. Biochar application on growth media in nursery also gave high survival for Dipterocarps seedlings (Marjenah et al. 2016; Syahrinudin et al. 2018). These demonstrate that the use of biochar as main media for raising seedlings in nursery is of interest for the replacement of the conventional media as the availability of these conventional media (topsoils) becoming scarce lately and the use of these conventional media subject to ecological degradation of its origin-removing fertile topsoil from the system may lead to nutrient cycle disruption and nutrient shortage of the system. The importance of biochar on plant survival is mostly driven by the improvement of plant water availability, aeration, porosity, nutrient retention and holding capacity to promote optimum utilization of root zone resources. Moreover, biochar application leads to the improvement of plant tolerance to salinity (Ali et al. 2017; Farhangi-Abriz and Torabian 2017; Kim et al. 2016), resistant on diseases (Mehari et al. 2015; Huang et al. 2015), drought-resistant (Kammann et al. 2011; Haider et al. 2014; Ali et al. 2017; Egamberdieva et al. 2017) and heavy metals and toxic elements resistance (Zheng et al. 2012; Gartler et al. 2013; Rizwan et al. 2015; Rees et al. 2015).

Table 2. Survival of 3-months-old seedlings after treatments (mean values followed by different letters are significant at $p < 0.05$; 0 and 1 in enrichment column represent without and with nutrient enrichment, respectively

Treatment			Survival	
Code	Biochar (%v)	Enrichment	Mean	STD
Interaction (A x B)			%	
A0B0	0	0	97.0	0.02
A0B1	0	1	97.0	0.02
A1B0	2	0	98.0	0.02
A1B1	2	1	100.0	0.00
A2B0	5	0	98.0	0.02
A2B1	5	1	100.0	0.00
A3B0	10	0	93.0	0.05
A3B1	10	1	98.0	0.02
A4B0	25	0	93.0	0.05
A4B1	25	1	98.0	0.02
A5B0	100	0	92.0	0.07
A5B1	100	1	98.0	0.02
Factor A (Rate of biochar)				
A0	0	-	97.0	0.02
A1	2	-	99.0	0.01
A2	5	-	99.0	0.01
A3	10	-	95.5	0.04
A4	25	-	95.5	0.04
A5	100	-	95.0	0.05
Factor B (Enrichment)				
B0	-	0	95^{a}	2.8
B1	-	1	99^{b}	1.2

Table 3. Height of 3-months-old seedlings after treatment (mean values followed by different letters are significant at $p < 0.05$; 0 and 1 in enrichment column represent without and with nutrient enrichment, respectively

Treatment			Seedling height	
Code	Biochar (%v)	Enrichment	Mean	STD
Interaction (A x B)			cm	
A0B0	0	0	6.2^{ab}	1.2
A0B1	0	1	6.2^{ab}	1.2
A1B0	2	0	13.6^{bc}	4.2
A1B1	2	1	13.2^{bc}	2.5
A2B0	5	0	9.7^{b}	1.0
A2B1	5	1	14.7^{c}	2.3
A3B0	10	0	15.7^{c}	0.7
A3B1	10	1	23.1^{d}	2.6
A4B0	25	0	10.6^{b}	3.4
A4B1	25	1	23.9^{d}	3.0
A5B0	100	0	4.8^{a}	1.5
A5B1	100	1	17.1^{c}	1.4
Factor A (Rate of biochar)				
A0	0	-	6.2^{a}	1.1
A1	2	-	13.4^{b}	7.3
A2	5	-	12.2^{b}	3.2
A3	10	-	19.4^{c}	4.4
A4	25	-	17.3^{c}	7.8
A5	100	-	10.9^{b}	6.9
Factor B (Enrichment)				
B0	-	0	10.1^{a}	4.4
B1	-	1	16.4^{b}	6.5

The environment is a complex of so many factors interrelated, soil is vitally important for plant growth and development. Soil represents a complicated physical, chemical, and biological system by which the plant is supplied with the water, nutrients, and oxygen. Biochar amendment may improve the physical properties of soil, i.e. bulk density, porosity, water holding capacity, available water, infiltration, permeability, structure formation and stability (Herath et al. 2013; Darusman et al. 2017; Mahmoud et al. 2017), chemical properties, i.e. increased the pH, CEC, nutrient retention (Hossain et al. 2010; Silber et al. 2010; Fernandes et al. 2018) and biological properties, i.e. microbial population and activities, microbial structure (Graber et al. 2010; Kolton et al. 2011; Luo et al. 2018) to promote better use of plant root zone which in turn enhance plant growth and quality.

The average plant height increased in line with the age of the plant till the end of observation period (3 months after replanting). The difference in the height 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 on growth media of 100% biochar treatment, the average height of plants in all media receiving biochar treatment was higher than that without biochar (Table 3), with application of 25%v enriched biochar gave the highest seedlings height, $p < 0.01$.

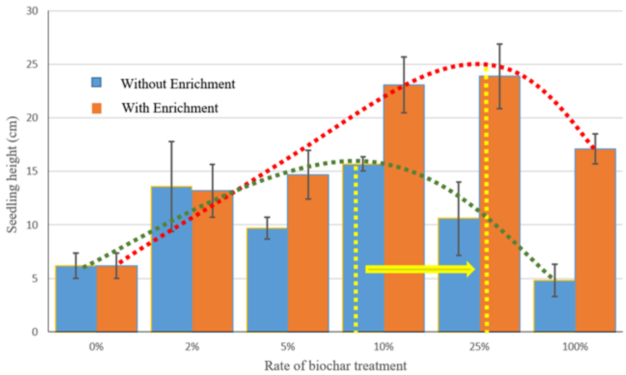

Figure 2. The effect of biochar application and nutrient enrichment of the height of seedlings. Stack bars represent standard deviations of the respective means

Biochar alone (without nutrient enrichment) improved the growth rate of seedlings by 253% compared to the control treatment (without biochar) at application rate of 10%v biochar, enrichment of biochar lifted up effect of biochar application on height growth rate of seedling to 386% compared to the control treatment at application rate of 25% of biochar (Figure 2). It is interesting that enriched biochar not only improved the growth rate response but also carrying capacity of soils to biochar treatment from about 10%v to somewhere around 25%v (Figure 2).

Biochar modifies the environmental conditions of the growing media through improvement of aeration, water availability attributed to its high porosity and low bulk density (Abel et al 2013; Herath et al 2013; Pratiwi and Shinogi 2016), soil reactions, microorganism activity in the soil and availability of plant nutrients attributed its chemical properties, i.e. high surface area, liming effect and nutrient content of biochar (Major et al. 2010; Dharmakeerthi et al. 2012) to facilitate the optimal utilization of the resources of plant roots environment which in turn will increase plant growth. However, at higher biochar applications (i.e. 25%v and 100%v), height growth rate of *A. cadamba* seedlings decreased, which may be attributed to the nutrient immobilization by microorganisms consuming volatile matter in biochar (Sun et al. 2015; Kanouo et al. 2017). Figure 2 implies that application of enriched biochar may further improve soil carbon sequestration potential to more than two-fold of that of without enrichment. Soil organic carbon (SOC) is the main factor affecting soil quality and agriculture sustainability. Being a source and sink of plant nutrients, SOC plays an important role in terrestrial C and nutrient cycle (Freixo et al. 2002). Carbon sequestrations in agricultural soils is of significant importance for atmospheric carbon dioxide mitigation and soil fertility enhancement (Glaser et al. 2002; Lehmann 2007). Traditional soil organic carbon (SOC) enrichment practices involving biomass residues incorporation and green manures lead to rapid mineralization releasing CO_2 to atmosphere (Sauerbeck 2001; Lehmann et al. 2006; Baker et al. 2007; Bruun et al. 2011) beside subject to the enhancement of methane and nitrous oxide emission (Palumbo et al. 2004; Reijnders 2009) contributing to higher global warming potential. In contrast to traditional organic materials, biochar is a highly carbonized material produced by pyrolysis, consisting of large extent of aromatic compounds that are resistant to biological degradation (Baldock and Smernik 2002). Biochar may stay in soils for hundreds to thousands of years (Lal 2003; Kuzyakov et al. 2009). Therefore, biochar application is a promising alternative to sequester more C in soils compared to traditional practices and rated as the best geoengineering option for carbon sequestration (Lenton and Vaughan 2009). Large-scale biochar application will lead to the increase of soil carbon pool contributing to climate change mitigation (Ameloot et al. 2013).

Diameter growth rate of *A. cadamba* seedlings showed similar manner to that of height growth rate, but less pronounce and higher preference to biochar application level (Table 4). Both factors, rate of biochar treatment and biochar enrichment, as well as the interaction gave significant effect on diameter growth rate of *A. cadamba* seedlings grown in spodosols in pots experiment. 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, with application of 25%v biochar gave highest seedlings diameter, $p < 0.01$. Growth rate of seedling diameter showed positive response to wide range of biochar application level. Biochar alone improved growth rate of seedlings diameter by 116% compared to the control treatment (without biochar) at application rate of 25%v biochar. The application of biochar may significantly increase the soil pH towards neutralize and reduce soil exchangeable acidity (Xu et al. 2012; Yuan et al. 2011). During the pyrolysis of biomass materials, most of the micro-and macronutrients were segregated into biochar fractions. When it is applied to the acid soils, the basic cation, especially Ca^{2+}, can exchange with Al^{3+} and H^+ on the soil exchange sites. Due to these mechanisms, soil exchangeable acidity is reduced while soil exchangeable basicity (basic cations) is enhanced (Lehmann et al. 2003). Growth improvement of seedlings may also be attributable to the pore distribution improvement of growth media. Positive effect of biochar on soil bulk density is mainly the result of the dilution effect of biochar having higher porosity and soil aggregation (Mukome et al. 2013; Zong et al. 2014).

Enrichment of biochar lifted up the effect of biochar application on diameter growth rate of seedlings to 150% of the control treatment at application rate of 100% of biochar. It is interesting that enriched biochar not only improves growth rate response but also carrying capacity of soils to biochar treatment from about 25%v to 100%v. The applications of liquid organic fertilizers may significantly improve the nutrient level, i.e. mineral N, available P, and available K contents (Ji et al. 2017) attributed to the

Table 4. Diameter of 3-months-old seedlings after treatment (mean values followed by different letters are significant at $p < 0.05$; 0 and 1 in enrichment column represent without and with nutrient enrichment, respectively

Treatment			Seedling diameter	
Code	Biochar (%v)	Enrichment	Mean (mm)	STD
Interaction (A x B)				
A0B0	0	0	2.11^{a}	0.02
A0B1	0	1	2.11^{a}	0.02
A1B0	2	0	2.14^{a}	0.05
A1B1	2	1	2.37^{b}	0.10
A2B0	5	0	2.12^{a}	0.11
A2B1	5	1	2.44^{b}	0.05
A3B0	10	0	2.16^{ab}	0.23
A3B1	10	1	2.80^{c}	0.13
A4B0	25	0	2.44^{b}	0.14
A4B1	25	1	3.10^{d}	0.12
A5B0	100	0	2.14^{a}	0.47
A5B1	100	1	3.17^{d}	0.04
Factor A (rate of biochar)				
A0	0	-	2.11^{a}	0.02
A1	2	-	2.26^{a}	0.95
A2	5	-	2.28^{ab}	0.19
A3	10	-	2.48^{b}	0.39
A4	25	-	2.77^{c}	0.38
A5	100	-	2.65^{bc}	0.64
Factor B (enrichment)				
B0	-	0	2.19^{a}	0.22
B1	-	1	2.66^{b}	0.41

improved diversity of the microbial community, which enhances the nutrient cycle in the soil (Lee et al. 2004; Zhu et al. 2013). Even though the diameter growth rate response of *A. cadamba* seedlings to application of 100% biochar treatment alone was less pronounced, the enrichment of nutrients into biochar gave tremendous improvement in diameter growth rate of seedlings. Here again, our results suggested that the use of biochar for major plant growth media in raising seedling in nursery is promising.

Biomass growth rate of *A. cadamba* seedlings showed similar manner to that of diameter growth rate, but in contrast to height growth rate, biomass growth rate showed good preference to higher rate of biochar application-level especially for those with enrichment (Figure 3). Both factors, rate of biochar treatment and nutrient enrichment gave significant effect on biomass growth rate of *A. cadamba* seedlings grown in spodosols in pots experiment. However, interaction of the treatments gave significant effect as well. At the end of the observation period, three months after replanting, excluding the application of 100% biochar without enrichment, the average of plant biomass in all media receiving biochar treatment was higher than that without biochar with application of 100%v biochar gave the highest seedlings biomass, $p < 0.01$. In line with diameter growth rate, growth rate of seedling biomass showed positive response to wide range of biochar application levels. Biochar alone improved growth rate of seedlings shoot and root biomass by 124% and 168% of the control treatment (without biochar) at application rate of 15%v and 10% biochar, respectively. Enrichment of organic nutrients into biochar lifted up the effect of biochar application on shoot and root biomass growth rate of seedling to 214% and 364% of the control treatment at application rate of 100% of biochar, respectively. Response of seedling biomass growth rate to enriched biochar application confirmed that of height and diameter growth rate of seedlings that enriched biochar not only improved growth rate but also carrying capacity of soils to biochar treatment from about 15%v to 100%v. In the similar ways as to diameter growth rate, the response of *A. cadamba* seedlings to application of biochar treatment alone was less pronounce, biochar enriched with organic fertilizers gave tremendous improvement in biomass growth rate of seedlings. Regression analysis showed that there is high dependency of root biomass growth rate on the application rate of enriched biochar ($r^2 = 0.98$, $p < 0.01$), and shoot biomass growth rate of all treatment highly correlated to the root biomass growth rate of the seedling ($r^2 = 0.74$, $p < 0.01$), thus the overall biomass growth rate was highly affected by biochar application. This may imply that the use of biochar for major plant growth media in raising seedling in nursery is promising.

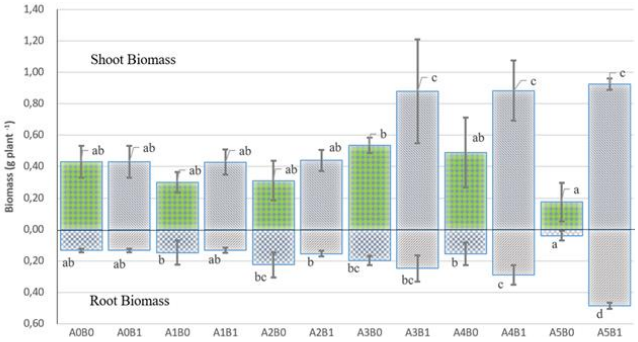

Figure 3. Biomass growth rate response of seedlings to biochar application; A0, A1, A2, A3, A4, and A5 represent biochar application of 0%v, 2%v, 5%v, 10%v, 25%v and 100%v, respectively; B0 and B1 represent without nutrient enrichment and with nutrient enrichment, respectively; stack bars are standard deviations of the respective means.

In conclusion, biochar application on degraded spodosols is of utmost interest not only driven by soil organic carbon sequestration potential of biochar in such ecosystems but also by the amendment capacity of biochar to improve soil fertility and facilitate favorable root zone conditions for optimum utilization by plants. Biochar application alone improved height and diameter growth rate of *A. cadamba* seedlings by 253% and 116% of control treatment (without biochar), respectively. Enrichment of organic fertilizers gave further improvement in height and diameter growth rate of *A. cadamba* seedlings to 386% and 150% of control treatment (without biochar), respectively. Furthermore, biochar application improved survival and biomass growth rate of the seedlings. Enrichment of organic fertilizers into biochar improved not only seedling growth rate but also more interestingly carrying capacity of spodosols to biochar application rate. Therefore, a lot more biochar could be applied to such soils and higher atmospheric carbon dioxide mitigation could be achieved. This study suggests that the use of biochar enriched with organic fertilizers as media to grow seedling in nursery is promising.

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