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Application of Biochar and Organic Fertilizer on Acid Soil as Growing Medium for Cacao (*Theobroma cacao* L.) Seedlings

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Abstract

The use of infertile acidic soil as a nursery growing medium has several limiting factors for plant growth. Application of ameliorant is an efforts to improve the quality of growing medium both the chemical, physical, and biological properties and increase seedling growth. This study was aimed to investigate the effect of biochar and organic fertilizer to the chemical properties of the growing medium and cacao seedling biomass. The study was a factorial treatment consisting three factors in a completely randomized design with three replications. The first factor was organic fertilizer treatment (without organic fertilizer and with 10% (w/w) organic fertilizer). The second factor was the types of biochar (rice husk biochar and white albizia wood biochar). The third factor was the rates of biochar application (0%, 1%, 2%, 4%, 6% w/w). The research was an incubation of growing medium for 15 days after treatments, then followed by cacao seedlings for 20 weeks.

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The results showed that the increase of biochar rate and organic fertilizers application increased available P and exchangeable base cations (K, Ca, Na), whilst decreased exchangeable Al of the medium. The increase of biochar rate without organic fertilizer decreased the total dry weight of cacao seedling. However, the increase of biochar rate in combination with organic fertilizers increased linearly the dry weight of leaves and total dry weight of cacao seedlings.

Keywords: acid soil; biochar; cacao seedling; organic fertilizer.

1. Introduction

Cacao (*Theobroma cacao* L.) is one of the main commodities in Indonesia which became the third largest foreign exchange earner after palm oil and rubber. Cacao in Indonesia was developed on various soil types, including on acid soils. Acid soils occupied large areas of Indonesia and some areas have been utilized for annual crops development. The rejuvenation and expansion of cacao plantations in acid soils were implemented to increase national cacao production. The development of cacao plantation in acid soils faces low soil fertility constraints. Acid soils typically have several limiting factors for plant growth ie low pH <5.5, high exchangeable Al content, high P fixation, and low content of exchangeable cation such as Ca, K, and Mg [1]. Aluminum toxicity and nutrient deficiency could inhibit the growth of cacao plants on acid soils [2].

The effort to improve the quality of acid soils as a medium of cacao planting needs to be done from the nursery until field planting. The ameliorant application in acid soil for nursery is aimed to produce high quality of seedlings. Amelioration with organic material can supply organic matter and improve soil chemical, physical and biological properties. Cacao growth in acid soil is very responsive to the ameliorant application that improve the quality of growing media [3]. The utilization of organic fertilizer from cacao pod husk as growing medium can produce better growth of cacao seedlings [4]. The other ameliorant that potentially could be utilized for the improvement of acid soil properties is biochar. Biochar is a carbon-rich material produced by heating of biomass with a limited supply of oxygen (pyrolysis). Application biochar in agriculture field was inspired by the Amazonian Dark Earth (Terra Preta), which had a high level of soil organic matter and available nutrient [5]. Biochar typically has the high porosity, surface areas, and pH, and contains the nutrients, therefore biochar application in acid soil can improve soil chemical [6], soil physical [7], and soil biological quality [8]. Some references reported that the effect of biochar on crop productivity (dry weight and crop yield) varies considerably. There is a positive or negative effects of rising biochar as ameliorant depending on the properties and rates of biochar, soil properties, plant types, and other inputs [9, 10, 11, 12, 7]. The effects of biochar on the plant growth related to the ash and volatil matter content which depend to the degree of temperature of biochar production [11, 13]. The biochar were produced from low pyrolysis temperatures had a high volatile material content, which could have a negative effect on plant growth [11].

Combination biochar with organic fertilizer could reduce negative effects of fresh biochar [14]. Several studies reported the positive effects of biochar and compost on soil fertility and productivity of crops [15, 16, 17]. The information about the effect of biochar both alone application or in combination with organic fertilizer on the acid soil properties and the growth of cacao seedlings still limited. Therefore, this study was aimed to investigate the effect of biochar and organic fertilizer on: (1) chemical properties of growing medium from acid soil and (2) cacao seedlings biomass. This study can be a preliminary research for the further utilization of biochar in cacao plantations at the acid soil.

2. Materials and Methods

The study was conducted in the experimental garden of Indonesian Industrial and Beverage Crops Research Institute, Sukabumi, Indonesia. This study was conducted from August 2014 to May 2015. The soil for medium was *Typic Hapludults* from Jasinga, West Java, Indonesia. Two biochar for trial were made from rice husk and white albizia wood. The biochars were produced using drums that were modified into pyrolysis reactors by pirolysis temperature at 350 – 400^{o}C. Both biochars were crushed and subsequently sieved to pass through a 2-mm sieve. The organic fertilizer was made from the mixture of cacao pod husk and cow dung 2 : 1 (w/w).

The study was a factorial treatment consisting three factors in a completely randomized design with three replications, and each replication was consisted of three seedlings. The first factor was organic fertilizer treatment (without organic fertilizer and with 10% (w/w) organic fertilizer). The second factor was the types of biochar (rice husk biochar (Brh) and white albizia wood biochar (Baw)).

The third factor was the rates of biochar application (0%, 1%, 2%, 4%, 6% w/w). The total weight of medium on each polybag is 2.2 kg absolute dry weight. Soil was mixed with biochar and/or organic fertilizer, and then transferred into a polybag. The study was carried out by incubation of growing medium for 15 days, and then evaluation of the growth of cacao seedlings for 20 weeks. Samples of medium were collected from each polybag after 15 days incubation, and air dried, crushed, and passed through 2 mm sieve before analysis.

Chemical properties of growing media which measured, ie available P (Bray 1), exchangeable base cations, cation exchange capacity (CEC) and exchangeable Al of the medium. After 15 days incubation, all polybag were applied the basic fertilizer ie Urea 2 g N per polybag, SP-36 2 g P_2O_5 per polybag and KCl 2 g K_2O per polybag based on recommendation doses [18]. Furthermore, cacao seeds are planted in polybags and the maintenance of seedlings until 20 weeks include: watering, manual weed control, and chemically disease control.

The observed variables were the dry weight of leaves and total dry weight of cacao seedlings. The result of soil analysis and plant observation were analyzed by a two-way analysis of variance (ANOVA) and LSD test at α 5%. The soil properties and plant response to the increased rate of biochar application were tested with Orthogonal polynomials [19].

3. Results and Discussion

3.1. Soil and ameliorant properties

The chemical properties of soil were used in this study are presented in Table 1. This soil has several fertility constraints: very acidic soil, high exchangeable Al content, low exchangeable base cations content (K, Ca, Na).

Table 1: Selected soil properties

pH (H_2O)	Organic C (%)	Total N (%)	Available P (mg kg^{-1})	Exch. Al (cmol kg^{-1})	Exch. K	Exch. Ca	Exch. Mg	Exch. Na	CEC
					……………. (cmol (+) kg^{-1})………………..				
3.90	1.60	0.26	1.77	19.82	0.27	1.62	1.68	0.2	26.36

Aluminum (Al) toxicity is a main factor limiting plant growth in acidic soil especially cacao crops, therefore the amelioration needs to be applied in this soil to alleviate the Al toxicity, increase pH and nutrient availability and improve the other soil properties. Chemical properties of rice husk biochar, white albizia wood biochar, and organic fertilizer were used in this study are presented in Table 2. The differences in the properties of both biochars were determined by the types of raw material. White albizia wood biochar has a total C, total Ca content, and pH value was relatively higher than rice husk biochar. While rice husk biochar has total N and ash content higher than white albizia wood biochar. Rice husk biochar has a high ash content due to its high silica content. Ash on rice husk biochar contains silica oxide as the main component while other compounds such as CaO, MgO, K_2O, and Na_2O are relatively small [20]. The organic fertilizer has a pH value, N, P, K, Ca, Mg, Na total content, and CEC higher than rice husk biochar and white albizia wood biochar.

Table 2: Chemical properties of organic fertilizer, rice husk biochar, and white albizia wood biochar

Parameter	Rice husk biochar	White albizia wood biochar	Organic fertilizer
Water content (%)	7.53	13.93	24.33
pH H_2O	7.0	7.9	8.5
Total N (%)	0.83	0.73	1.87
Total C (%)	40.24	92.34	38.73
C/N ratio	48.5	126.5	20.7
CEC (cmol(+) kg^{-1})	14.52	18.48	66.09
Total P (%)	0.15	0.10	0.57
Total K (%)	0.48	0.77	4.62
Total Ca (%)	0.17	0.60	1.03
Total Mg (%)	0.13	0.16	0.97
Total Na (%)	0.14	0.25	1.43
Volatil matter (%)	31.00	71.81	na
Ash content (%)	46.52	5.98	33.22
Fixed C (%)	22.48	22.21	-

na: non analyzed

3.2. Effect of biochar and organic fertilizer on chemical properties of growing medium

The effect of biochar and organic fertilizers on the pH value, N total, organic C, and soil biological properties in this study has been reported by [21]. The pH value, total N and organik C content in the growing medium increased significantly by the application of biochar and organic fertilizer in 15 days incubation. The content of available P in the growing medium was affected by the interaction of types and rates of biochar and organic fertilizer treatment (Figure 1).

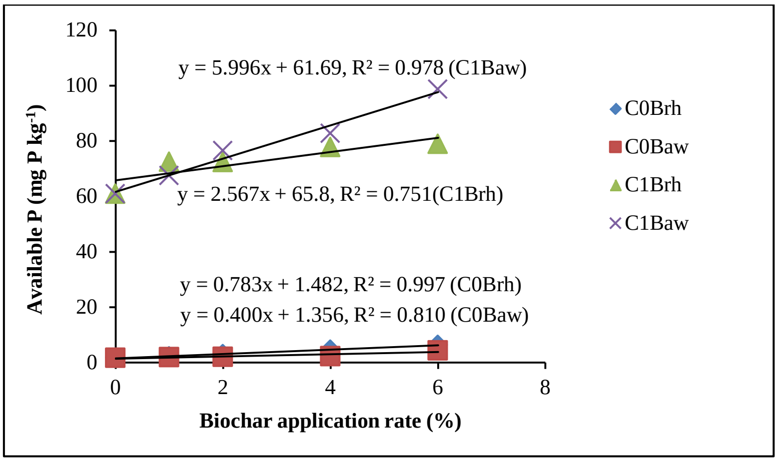

Figure 1: Effect of types and rates of biochar and organic fertilizer treatment on the available P of growing medium. C0: without organic fertilizer, C1: with 10% (w/w) organic fertilizer, Brh: rice husk biochar, Baw: white albizia wood biochar

The increase of biochar rates both rice husk or white albizia wood biochar increased linearly the available P in the medium with or without organic fertilizer (Figure 1). The addition of organic fertilizer also increased significantly available P from 1.62 mg P kg^{-1} (low) to 60.89 mg P kg^{-1} (very high). Organic fertilizer supplied organic P which can be hydrolyzed and mineralized to the orthophosphate ions which available to the plant. The combination of white albizia biochar and organic fertilizer resulted the higher available P than the combination rice husk biochar and organic fertilizer. The increase of biochar rates on medium with organic fertilizer increased availabe P more effectively than in the medium without organic fertilizer. These results indicated that there was a synergistic effect between biochar and organic fertilizer in increasing the availability of P. The biochar affected the availability of P in the soil through several mechanisms, ie biochar as a direct source of soluble P and exchangeable P, biochar increased the soil pH, biochar as ameliorator of P complexing metal (Al, Fe, and Ca), and biochar promotes the microbial activity in the P cycle [22, 23]. Biochar increased the water soluble P, however some P dissolved from the biochar could be retained and adsorbed by clay mineral, organic matter, and Al^{3+} and $Fe^{2+}/^{3+}$ site and flocculated by cations added from the biochar [24]. Whilst, the organic fertilizer contribute in increasing P mobilisation and decreasing P fixation through several mechanisms ie: 1) increase in soil pH to decrease P adsorption by Al and Fe, 2) reducing the fixation of P on the soil by release or production of organic acids competing with phosphates in the adsorption site in colloids and complex cations such as Al and Fe, 3) stimulation of microbial activity that plays a role in organic P mineralization and inorganic P dissolution [25, 26]. There was significant interaction between the rates of biochar and organic fertilizer treatment to exchangeable Al (Figure 2a). The application of biochar and/or organic fertilizer decreased significantly the content of exchangeable Al. The increase of biochar rate decreased linearly the exchangeable Al content on medium without organic fertilizer and with organic fertilizer. The ability of organic fertilizer 10% was higher in reducing the content of exchangeable Al than the highest biochar rate (6%). Addition of organic fertilizer reduced exchangeable Al from 18.29 to 2.80 cmol (+) kg^{-1} on medium with organic fertilizer only while 6% biochar application reduced exchangeable Al from 18.29 to 14.41 cmol (+) kg^{-1} on medium with biochar only. Organic fertilizers reduced the exchangeable Al by increasing soil pH, simultaneous chelation, complex formation, adsorption, and precipitation Al [14]. Biochar reduced the content of exchangeable Al because of liming effect from biochar, it is also reported by [6] and [27]. The reduction of exchangeable Al in soil by biochar due to the oxide contained in ash can react with H^+ and Al monomeric, modifying soil pH and exchangeable acidity values [28]. In addition, according to [27], the reduction of the exchangeable Al content by biochar can also be through the mechanism of formation of Al complex by oxidized organic functional groups particularly carboxylics and phenolic at the biochar surface.

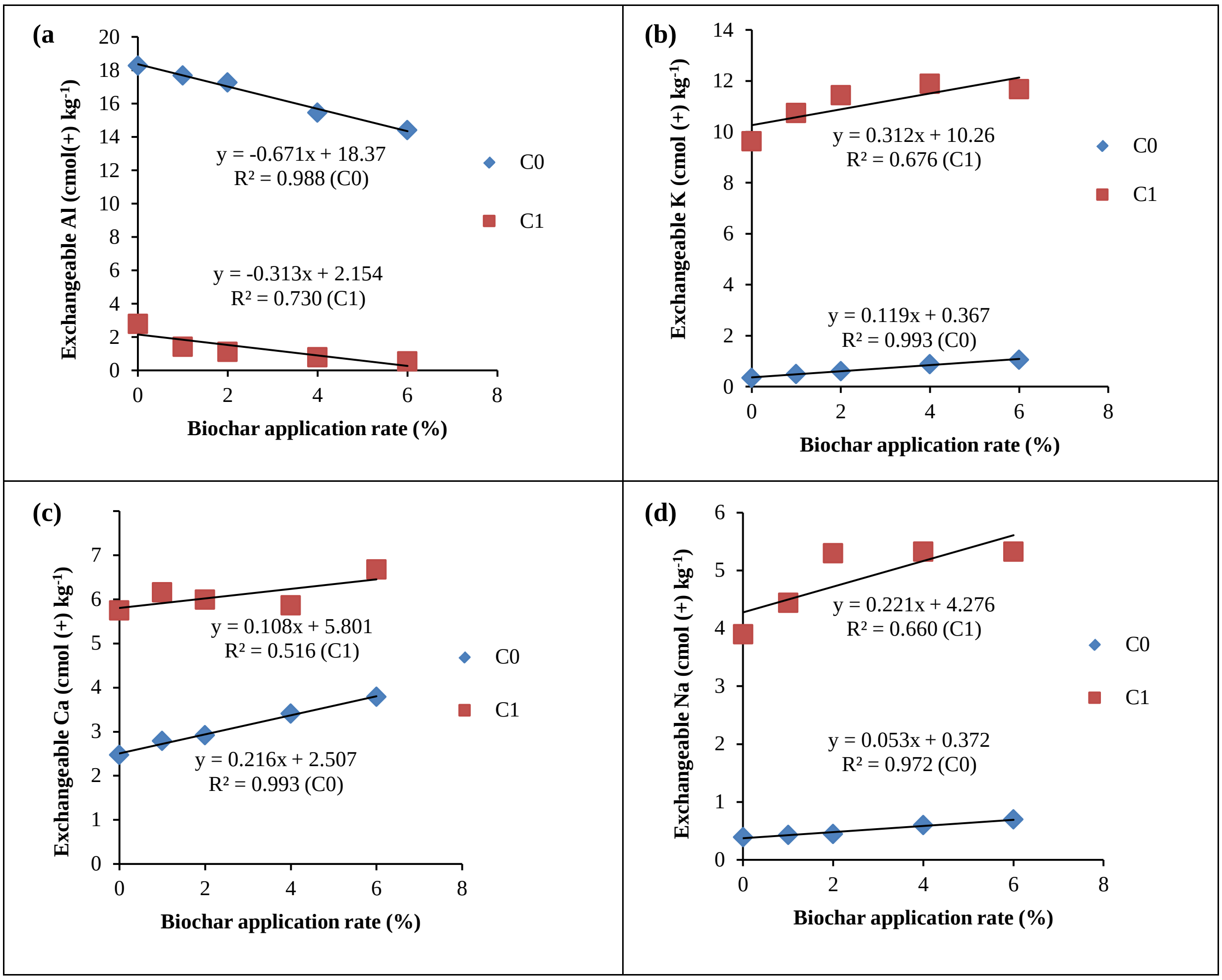

Figure 2: Effect of biochar application rates and organic fertilizer on: (a) exchangeable Al , (b) exchangeable K, (c) exchangeable Ca, (d) exchangeable Na of growing medium. C0: without organic fertilizer, C1: with 10% (w/w) organic fertilizer.

The exchangeable base cation content K, Ca, and Na were affected significantly by interaction between biochar application rates and organic fertilizer (Figure 2b, 2c, 2d). The increase of biochar rate increased linearly exchangeable K, Ca, and Na on medium without or with organic fertilizer. The addition of biochar not significant affected on exchangeable Mg in growing media due to the low of Mg content in biochar (Table 3). The increases in exchangeable K, Ca, and Na by increasing of biochar rates were due to the presence of the nutrients in the biochar. Biochar increased nutrients directly, by dissolving ash from biochar residues and other nutrients that may be available from microbial activity [29].

Rice husk biochar and white albizia wood biochar significantly different in effecting exchangeable Ca content in growing medium (Figure 3). The increase of white albizia wood biochar rates increased linearly exchangeable Ca, while rice husk charcoal did not significant effect compared to the control (without biochar). These result were due to higher content of the total Ca in white albizia wood biochar than rice husk biochar (Table 2).

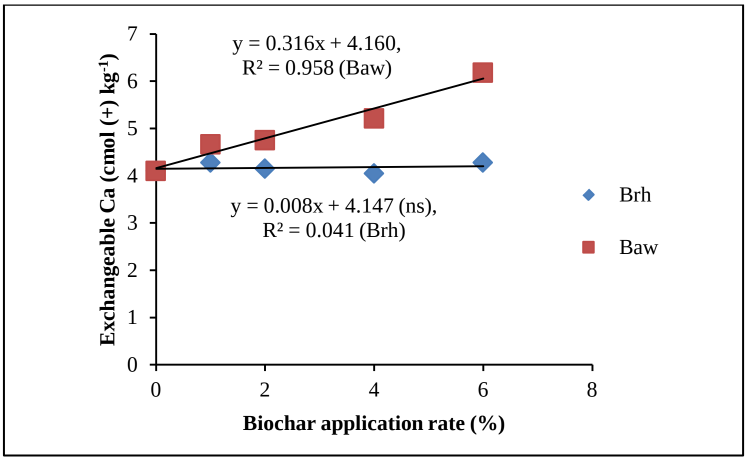

Figure 3: Effect of types and rates of biochar on exchangeable Ca of growing medium. Brh: rice husk biochar, Baw: white albizia wood biochar

Types and rates of biochar application non significantly affected on CEC in growing media (Table 3). Similar result also reported by [28] that the addition of biochar not significant increased the CEC of soil. The author in [30] reported that effective CEC increased significantly in soils treated with high amounts of biochar (10% and 20% w/w) during 500 days incubation, however at lower application rates (5% w/w), there was no effect on effective CEC. The study by [27] also showed that 8% lac tree wood 600 biochar and 8% rice husk biochar could significantly increase CEC of acid soil from Jasinga after incubated 34 days. However, this study resulted that application of 6% biochars (rice husk biochar and white albizia wood biochar) in short-term incubation (15 days) was no effect on the CEC of growth medium (Table 3). The incubation time in this study was conducted in the short term, so the application of biochar has not changes the CEC of growing medium. The author in [31] reported that fresh biochar may have relatively low CEC values but the CEC increases gradually on incubation in soil due to oxidation of the biochar surfaces and/or adsorption of organic acids by the biochar.

Organic fertilizer application increased the exchangeable base cation content (K, Ca, Na) to high nutrient level of growing medium (Figure 2b, 2c, 2d). Organic fertilizer application also increased exchangeable Mg content and cation exchange capacity (CEC) in growing medium (Table 3). Organic fertilizer increased the CEC of medium from 33.07 cmol (+) kg^{-1} to 37.97 cmol (+) kg^{-1}. Organic fertilizer contains significant amounts of essential plant nutrients including N, P, K, Ca, Mg and S as well as a variety of essential trace elements. Organic ameliorant resulted in an increase of CEC due to input of stabilized organic matter being rich in functional groups into soil [15].

Table 3: Effect of organic fertilizer, types and rates of biochar on exchangeable Mg and cation exchange capacity (CEC) in growing medium

Treatment	Exchangeable Mg cmol (+) kg^{-1}	CEC cmol (+) kg^{-1}
Organic fertilizer :		
Without	1.61b	33.07b
10%	5.93a	37.97a
Rates of biochar :		
0%	3.58	36.39
1%	3.86	35.71
2%	3.78	35.62
4%	3.80	35.10
6%	3.84	34.79
Types of biochar :		
Brh	3.85	35.57
Baw	3.69	35.47

Note: The numbers in the same column followed by the same letter were not significantly different based on the LSD test at α 5%

The results of this study support several of previous studies which reported that biochar and organic fertilizer have positively affected the acid soil properties. The author in [3] also reported the application of organic fertilizer increased pH, nutrient availability (P, K, Ca, Mg), and reduced the toxicity of Al of acid soil for supporting the cacao growth. The authors in [6, 27] also reported that the applications of biochar also can improve chemical properties at acid soils in Indonesia, including: increase soil pH, decrease exchangeable Al, increase available P, exchangeable base cation, and content of organic matter. Biochar also has the capacity to absorb nutrients dissolved in the soil. The increased of nutrient content and nutrient retention capacity by biochar will increase nutrient supply for plants and reduce nutrient loss through leaching [5]. It is advantageous potentially when biochar is applied with inorganic or organic fertilizer as a source of nutrients, then biochar can reduce nutrient leaching.

3.3. Effect of biochar and organic fertilizer on dry weight of cacao seedling

This study shows that the addition of biochar alone without organic fertilizer significantly reduced total dry weight of cacao seedlings and not significantly reduced the dry weight of leaves (Table 4). Several studies have also reported a decrease in biomass and yields of crop due to biochar application [9, 11]. The addition of biochar without organic fertilizers in this study leads to a decrease in the dry weight of the plant possibly as a result of the high volatile matter content (Table 2) which could lead to N immobilization and could be toxic to the plant. The volatile organic compounds were contained in the biochar can affect plant growth through two mechanisms: toxic compounds such as phenol which can directly inhibit root growth, or oligosaccharides and phenols can provide labile C for microbes which inducing N immobilization [11].

It also shows that biochar alone did not succeed in improving the growth of cacao seedlings might be because of the slight improvement in soil quality by biochar. The soils was used in this study has a very low pH, high exchangeable Al content, low content of cation bases, and low available P, then biochar alone has not been able to overcome the limiting factors. In this study, application of biochar up to 6% without organic fertilizers still resulted the high exchangeable Al content of 14.41 cmol (+) kg^{-1}, therefore cacao growth was still limited by Al toxicity. Author in [2] reported that the high Al saturation significantly reduced shoot and root dry weight of cacao plant.

Table 4: Effect of biochar application rate and organic fertilizer on dry weight of leaves and total dry weight of cacao seedling

Organic fertilizer	Biochar application rate (%) w/w					Response curve
	0	1	2	4	6	
	Dry weight of leaves (g $seedling^{-1}$)					
without (C0)	5.94	5.56	5.11	5.08	4.61	-
10% (C1)	6.60	6.76	8.35	8.89	9.45	Linier (+)
	Total dry weight (g $seedling^{-1}$)					
without (C0)	11.11	10.09	9.40	9.70	8.55	Linier (-)
10% (C1)	10.56	11.92	13.93	15.31	15.11	Linier (+)

Note: The response curve to the rates of biochar application was analyzed by orthogonal polynomials test

The increase of the biochar rate in combination with organic fertilizers resulted a linear increase in the total dry weight of cacao seedlings. Application 6% biochar with organic fertilizer increased 36% total dry weight from medium without ameliorant. It shows that biochar affected positive to the growth of cacao seedlings if in combination with organic fertilizer. The authors in [17, 32, 33] also reported that the combination biochar and organic fertilizer resulted the higher of growth and yield of watermelon, Amaranthus cruentus and red chilli than biochar only or organic fertilizer only. Compost and biochar synergize in increasing the cacao seedlings growth due to the enhanced available nutrient supply from combined ameliorant. Organic fertilizer plays a role in increasing supply N for plant and microbial, so as to prevent the negative effect of N immobilization on the plant growth. Mixing of organic fertilizer and biochar might have a positive effect on the reduce of toxicity of volatile matter from biochar. Combination compost and biochar was reported could reduce nutrient leaching and improvement of soil structure and water balance by establishment of favorable soil pore structure [16].

4. Conclusion

The increase of biochar rates either alone or in combination with organic fertilizers increased the available P, exchangeable base cations (K, Ca, Na) and reduced exchangeable Al of the growing medium. The increase of the biochar rate in combination with organic fertilizers effectively increased the dry weight of leaves and total dry weight of cacao seedlings. Biochar affected positively to the growth of cacao seedlings if in combination with organic fertilizer.

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