The utilization of durian wood (*Durio zibethinus*) and corn cob (*Zea mays*) biochar on corn yields in acid sulphate soil

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Abstract. Biochar addition can be used to overcome the problem of acid sulphate soil. This study was aimed to analyze the effect of biochar dose on plant height and corn yield in acid sulphate soils. Durian wood waste and corn cob biochar used in this study was pyrolyzed for 2 hours at 550 °C temperature and ground until around 0.4-1.0 mm. The experiment was conducted in a screen house at the Indonesian Swampland Agriculture Research Institute. The experimental design used was a Completely Randomized Design consisting of six doses of biochar treatment with 3 replications. The total of 18 experimental pots was obtained with the following details: B1 0 t/ha, B2 4 t/ha, B3 8 t/ha, B4 12 t/ha, B5 16 t/ha and B6 20 t ha. Biochar treatment significantly affect plant height age of 2nd, 4th, 6th, 8th, 10th and 12th weeks. The longer the age, the higher the corn plant height. The corn cob length, corn cob diameter, dry weight of seed, and the dry water content significantly different in all treatments. The biochar dose significantly affected the corn yields. The best treatment of biochar in acid sulphate soil was obtained in 12 t ha⁻¹.

1. Introduction

Biochar is a subtle-grained carbonization product that has a high organic carbon content and low degradation susceptibility, obtained through biomass and biodegradable waste pyrolysis [1]. Biochar can be used for energy-related intention related to agriculture and environmental conservancy. Various kinds of biochar utilization continue to develop, especially in fields such as farming, industry, and operation linked with natural surroundings [2]. A modern approach to biochar production and utilization promising long-range agricultural advantages [3]. Biochar can be returned to the soil to restock nutrients and minerals. Hence it can increase the soil physicochemical features such as density, porosity, and pH. Biochar has also been found to absorb heavy metal and release macro- and micro-nutrients slowly [4] which can contribute to increasing fertilizer efficiency.

Biochar is produced through pyrolysis, it is heated without enough oxygen for complete combustion, removes various liquids and gases from the feedstock, and leaves a residue as biochar. Slow pyrolysis is the most effective pyrolysis because it results in a high yield of approximately 35.0% by weight of dry biomass [5]. There are many kinds of pyrolysis feedstocks, such as municipal waste, agricultural biomass, and forestry residue. Nowadays, the forestry residues can be used as a sustainable and reliable pyrolysis feedstock. The forestry residue has the most interesting characteristics as pyrolysis biomass since it has a sustainable supply system for large scale base, and raw materials suitability because of its features (low humidity, metal, and ash content) [4]. Biochar
derived from wood has a large potency to increase C storage in tropical soils because of its high C concentration, aromatic character, and low H/C ratio. The high of aromatic C content is due to the high amount of lignin and cellulose in wood biomass [6].

As soil amendment, biochar has been developed as a sustainable practice that simultaneously can mitigate climate change and improve the marginal soil quality [7]. There are lots of marginal land in Indonesia, such as tidal land, acidic and peat soils. The use of marginal land for crop cultivation has several obstacles that must be faced. Acid sulphate soils have been seen as one of the difficult soil to manage for crop production because of their low fertility, such as low soil pH and available phosphate and high Fe content [8]. The corn cultivation is very potential to be developed in acid sulphate soil. Soil acidity in acid sulphate soils is a main obstacle in the corn cultivation because it needs optimum soil pH at 5.6-7.5 for best growth. The high acidity in the soil will cause a deficiency of macronutrients such as potassium, magnesium, calcium, and phosphorus. The corns begin to suffer at pH 5.6, and can not survive at pH 4.0 [9]. Liming improves soil for the microbe habitat. They accelerate the decay of plant residues and release micronutrients, N, and P in the soil. Liming the acid sulphate soil can reduce the solubility of manganese and aluminum at low pH. Biochar, as liming material, can improve plant growth and crop yield. The fertilizer application can increase the corn yield as 4.4 t ha\(^{-1}\) [10]. Fertilizers that are combined with biochar can numerically increase corn yields. Based on Brantley [11], corn yields at fertile silt loam can increase at a dose of 5 and 10 Mg ha\(^{-1}\) of woodchip biochar in combination with N fertilizer. The addition of cow manure biochar at 15 t ha\(^{-1}\) and 20 t ha\(^{-1}\) in combination with NPK fertilizer significantly increased the corn yield of 150% and 98%, respectively in sandy soil [12]. This study was aimed to analyze the effect of biochar dose on plant height and corn yield in acid sulphate soils.

2. Materials and methods

2.1. Biochar production and properties
The method of biochar production was adopted from Setiawati [13]. Durian wood waste and corn cob as feedstock were collected from Banjarbaru, South Kalimantan, Indonesia. The feedstock was air-dried to remove moisture. Dry wood waste was then pyrolyzed at 550 °C with a holding time of 2 hours. The hot biochar was then quickly immersed by water. The biochar produced was then air-dried and grinded until around 0.4-1.0 mm to yield Durian Wood Biochar (DWB) and Corn Cob Biochar (CCB). Proximate and ultimate analyses of biochar included moisture content (MC, ASTM D.3173), pH (1:5 for biochar: water), volatile matter (VM, ASTM D.3175), fixed carbon (FC, ASTM D.3172), ash content (ASTM D.3174). Carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) were analyzed using ASTM D.5373, while oxygen (O) was computed according ASTM D.3176 by the sum of percentage of C, H, N, S, ash, subtracted from 100. The exchange cation capacity (CEC) was analyzed by using 1 M NH\(_4\)OAc extraction at pH 7.0. The biochar morphologies were analyzed by scanning electron microscope (SEM) method at 1000x magnification in the scales of 50 µm with an acceleration voltage of 15 kV. Fourier Transform Infrared (FT-IR) Spectrophotometer to analyze functional groups.

2.2. Soil used and experimental design
The acid sulphate soil was collected from Barambai, Barito Kuala District, South Kalimantan. The 30-50 cm depth layer soil had the following characteristics: pH (H\(_2\)O) 3.47; soil organic carbon (SOC) 4.50%; total N 0.246%; P\(_2\)O\(_5\) 105.15 mg 100g\(^{-1}\); K\(_2\)O 45.05 mg 100g\(^{-1}\); 64.23 mg 100g\(^{-1}\); exchangeable cations of Ca, Mg, K, Na, respectively, 0.21, 0.50, 0.82, and 0.52 me 100g\(^{-1}\) and CEC 20.34 me 100g\(^{-1}\). The soils were incorporated with 1 t ha\(^{-1}\) dolomite and 20 t ha\(^{-1}\) cow manure in all treatments one week before transplanting. Each biochar (DWP and CCB) was added to these soil based on each treatment rate.

The treatments of biochar added to soil were (1) Soil control (no biochar/B1); (2) Soil + 4 t ha\(^{-1}\) of biochar (B2); (3) Soil + 8 t ha\(^{-1}\) of biochar (B3); (4) Soil + 12 t ha\(^{-1}\) of biochar (B4); (5) Soil+16 t ha\(^{-1}\)
of biochar (B5); (6) Soil + 20 t ha\(^{-1}\) of biochar (B6). Each of the soil was put in a pot at the screen house. The hybrid corn seed, Bima 20 Uri, was then spread to the soils at the pot. The soil pH was analysed at the 4th, 8th, and 12th weeks. The growth of plant height was observed at the 2nd, 4th, 6th, 8th, 10th, and 12th weeks. The corn yield parameters included diameter parameters of cobs, cob length, dry seed shell weight, and dry water content.

2.3. Experimental design
The experimental design used in this study was a Completely Randomized Design (CRD) consisting of 6 (six) doses of biochar treatment of DWB and CCB with 3 replications. The analysis of data used SAS 9.1 software for windows by using the analysis of variance at the level of confidence at 5%. Difference between treatments for each parameter was analyzed by the Duncan's Multiple Range (DMRT) Test with a 5% confidence level [14].

3. Results and discussion

3.1. Biochar characteristics
Table 1 showed that the moisture content of corn cob durian (6.18%) was lower than the durian wood biochar (7.66%). The value of water content in biochar could be influenced by the drying process of biochar just after being immersed in water. Biochar for agricultural purposes should have a low water content because it could accelerate the absorption of nutrients and/or water [15]. The value of water content affected the ability of biochar to hold water. Biochar had the high ability to retain water to maintain soil moisture and create environmental carrying capacity [16].

Some research results concerning the pH value of biochar stated that biochar used as a soil conditioner should have an alkaline pH or above 7 [17,18]. These alkaline pH values indicated that both durian wood and corn cob biochars could also be used to reduce soil acidity. The corn cob biochar had a higher pH than that of durian wood (9.35 vs. 8.93, respectively), as well as a much higher CEC (25 vs. 24 me 100g\(^{-1}\), respectively). The high pH was due to the nutrient content of corn cob was higher than durian wood. Furthermore, high ash content of corn cob biochar also played a vital role in increasing the pH of biochar. High CEC in biochar indicated the ability to retain nutrients and water so that the water availability of plants was sufficient, especially for the process of plant physiology which necessary for plant height growth [19].

In biomass, volatile matters were methane, hydrocarbons, hydrogen, carbon monoxide, and non-combustible gases such as carbon dioxide and nitrogen. The content of VM durian wood biochar and corn cob biochar was (15.21 and 17.13)% The VM in biochar was composed of compounds other than water, ash, and carbon. It was consists of elements of hydrogen, hydrocarbons, CO\(_2\), CH\(_4\), methane, and carbon monoxide [15]. Therefore, the high or low value of VM in biochar was based on the chemical composition of extractive substances from its feedstock. Fixed-C showed that carbon had been converted to a more stable carbon which cannot be easily degraded. In line with the previous studies [13,15,20], the biochar FC of durian wood and corn cob was 71.9% and 70.37%.

The higher C concentration with a rise in pyrolysis temperature was due to a higher polymerization rate, resulted in a more condensed carbon structure in biochar. A similar result was reported for biochar produced by Domingues [6], biochar C contents in durian wood and corn cob were 79.88% and 81.13%. Yang [21] and Khodadad [22] found that biochar derived from wood at higher temperatures was more stable because it contains large amounts of aromatic organic matter compared to biochar made from agricultural residues when pyrolyzed at high temperature. An increase in the aromatic character of biochars was associated with dehydration reactions and removal of O and H functional groups, as well as the formation of aromatic structures [23]. The durian wood biochar had a higher H content than durian wood (11.09% vs. 10.23%, respectively), as well as a much higher O content (3.41% vs. 1.61%, respectively).
Table 1. Biochar characteristics.

| Testing parameter          | Durian wood | Corn cob |
|----------------------------|-------------|----------|
| Moisture content (%)       | 7.66        | 6.18     |
| pH                         | 8.93        | 9.35     |
| Ash content (%)            | 5.23        | 6.32     |
| Volatile matter (%)        | 15.21       | 17.13    |
| Fixed carbon (%)           | 71.9        | 70.37    |
| C (%)                      | 79.88       | 81.13    |
| H (%)                      | 11.09       | 10.23    |
| O (%)                      | 3.41        | 1.61     |
| N (%)                      | 0.36        | 0.65     |
| S (%)                      | 0.03        | 0.06     |
| CEC (me 100g⁻¹)            | 24.0        | 25.0     |

As seen in figure 1, there was the similarity of functional groups between durian wood biochar and corn cob biochar, which consisted of conjugated C-H bend (aromatic) at 862.88 cm⁻¹ - 758.74 cm⁻¹, while the other peaks showed the presence of cluster C=O stretch (in ketone) 1686.43 cm⁻¹, C=C stretch (aromatic) at 1570.71 cm⁻¹ - 1481.99 cm⁻¹, -CH₃ bend (in alkane) at 1481.99 cm⁻¹, and C-O stretch (in ether, ester, carboxylic acid, alcohol) at 1385.56 cm⁻¹ - 111.68 cm⁻¹. The higher number of C–H bend in durian wood biochar than corn cob biochar indicated that the durian wood biochar was more aromatic. The aromatic carbonyl (C-O) and carboxyl groups (C=O) were attributed to retained oxygen-containing organic groups in biochar produced. The broad peak of durian wood biochar at 3472.39 cm⁻¹ came from the feedstock, which was commonly found in lignin of phenolics (O-H stretch) [24].

Figure 1. FTIR spectrum of (a) durian wood biochar; (b) corn cob biochar.
3.2. Soil pH and growth plant height

Based on the results of a variety of analysis, it showed that the various doses of durian wood biochar and corn cob biochar on corn plants significantly affected the height of corn plants aged 2nd, 4th, 6th, 8th, 10th and 12th weeks of observation. The longer the observation, the higher the corn plant height. It could be stated that biochar addition can significantly influence plant growth [25]. The obtained results of plant growth indicated that the ameliorative effect of biochar was largely related with pH increase (table 2). The soil pH increased at biochar dose starting from 4 t ha⁻¹ (B2). In accordance with Manickam [7], the application of 4 t ha⁻¹ biochar combined with bio-fertilizer yielded a high increase in soil pH and crop yields.

**Table 2.** Soil pH of various biochar doses.

| Treatments | 4th week planting | 8th week planting | 12th week planting |
|------------|-------------------|-------------------|-------------------|
|            | DWB               | CCB               | DWB               | CCB               | DWB               | CCB               |
| B1         | 3.85ᵇ           | 3.93ᵇ             | 4.85ᶜ           | 5.05ᵇ           | 5.21ᶜ           | 5.41ᵇ             |
| B2         | 5.00ᵃ           | 4.97ᵇ             | 5.76ᵇ           | 5.48ᵇ           | 5.54ᵇ           | 5.76ᵇ             |
| B3         | 5.34ᵃ           | 5.45ᵃ             | 5.81ᵇ           | 5.78ᵃ           | 5.61ᵇ           | 5.58ᵇ             |
| B4         | 5.24ᵃ           | 5.29ᵃ             | 5.88ᵇ           | 5.61ᵇ           | 5.68ᵇ           | 5.85ᵇ             |
| B5         | 5.24ᵃ           | 5.62ᵇ             | 5.84ᵇ           | 6.03ᵃ           | 5.86ᵇ           | 5.98ᵇ             |
| B6         | 5.39ᵃ           | 5.60ᵃ             | 6.02ᵃ           | 6.12ᵇ           | 6.10ᵃ           | 6.51ᵃ             |

Remarks: Numbers followed by the different letter within each column were significantly different based on DMRT α = 5%

**Table 3.** Plant height of corn plant.

| Treatments | 2nd week planting | 4th week planting | 6th week planting | 8th week planting | 10th week planting | 12th week planting |
|------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|            | DWB               | CCB               | DWB               | CCB               | DWB               | CCB               |
| B1         | 35.8ᵇ           | 35.8ᵇ             | 67.0ᵃ           | 67.7ᵃ             | 98.7ᵇ           | 98.7ᵃ             | 121.8ᵇ           | 123.7ᶜ           | 144.2ᵇ           | 145.7ᵃ           | 115.0ᵇ           | 114.0ᵃ           |
| B2         | 34.0ᵇ           | 35.3ᵇ             | 58.3ᵇ           | 59.3ᵇ             | 101.0ᵇ          | 102.9ᵃ           | 119.2ᵈ           | 124.9ᵇ           | 137.3ᵇ           | 138.1ᵇ           | 130.7ᵇ           | 133.9ᵇ           |
| B3         | 39.3ᵇ           | 40.2ᵇ             | 76.4ᵇ           | 76.0ᵇ             | 109.0ᵇ          | 110.2ᵇ           | 120.7ᵈ           | 121.9ᵇ           | 132.3ᵈ           | 135.8ᵇ           | 140.0ᵇ           | 143.9ᵇ           |
| B4         | 39.7ᵇ           | 40.6ᵇ             | 78.0ᵇ           | 78.9ᵇ             | 112.7ᵇ          | 112.7ᵇ           | 126.3ᵇ           | 128.3ᵇ           | 140.0ᵇ           | 142.3ᵇ           | 144.9ᵇ           | 149.6ᵇ           |
| B5         | 43.7ᵃ           | 44.3ᵇ             | 79.0ᵇ           | 79.3ᵇ             | 112.0ᵇ          | 112.6ᵇ           | 126.0ᵇ           | 126.5ᵇ           | 140.0ᵇ           | 143.4ᵇ           | 130.3ᵈ           | 133.6ᵇ           |
| B6         | 45.2ᵃ           | 46.4ᵃ             | 83.3ᵇ           | 81.6ᵃ             | 124.0ᵇ          | 124.7ᵃ           | 132.7ᵇ           | 130.9ᵃ           | 141.2ᵇ           | 144.4ᵃ           | 135.0ᵇ           | 143.9ᵃ           |

Remarks: Numbers followed by the different letter within each column were significantly different based on DMRT α = 5%

Based on table 3, the results showed an increase in plant height at 2nd, 4th, 6th, 8th, 10th and 12th weeks of observation in all biochar doses, except in B2. The plant height decreased in 4 t ha⁻¹ at all of age planting periods in both DWB and CCB. Biochar dose of 4 t ha⁻¹ had the least effect to plant growth. In line with Alvum-Toll [26], the low dose of biochar was not significantly different from the zero dose in plant height. During the first 1-2 weeks after planting, seeds provided food reserves for plant growth. In line with the development of the root system and decrease in food reserves in the seeds then the roots were immediately obtained following their functions. The growing point was 2-3 cm below the surface of the soil in the 3-4 week planting periods. In the first growing season at 3-4 week periods, plant height increased with the application of biochar.

3.3. Corn yield

Based on the study results, it showed that the corn cob length, corn cob diameter, dry weight of seed, and dry water content significantly different in all treatments. The biochar dose significantly affected
the corn yields. The corn cob length was (11.20-14.14) cm for DWB treatment and (10.98-114.67) cm for CCB treatment. The diameter of corn cobs was (3.14-3.55) cm for DWB and (3.23-3.67) cm for CCB. The dry weight of seed was (26.77-50.68) gr for DWB and (27.17-51.23) gr for CCB. The dry water content was (13.17-15.50) % for DWB and (13.24-14.56) % for CCB.

The biochar could increase crop yield. The presence of cow manure as compost could improve productivity. The compost showed the existence of microbiological characteristics that the potential to be used as a soil conditioner. The combination of compost and biochar seemed to increase added value. It was proved in this study, which B2-B6 had a better yield performance than B1. In line with Trupiano [27] which stated that a combination of biochar and organic fertilizers (compost) which provides important nutrients for plants could increase soil fertility and crop yield. Compared to B1, the increasing of corn cob length was 12.28% - 26.5% for DWB and 25.3%-33.6% for CCB (Figure 2a), the corn cob diameter was 1.8%-13.1% for DWB and 8.4%-13.6% for CCB (Figure 2b), the dry weight of seed was 13.1-89.3% for DWB and 27.2-88.6% for CCB (Figure 2c), while the dry water content of corn was decreased by 5.6%-15.1% for DWB and 4.0%-9.1% for CCB.

Figure 2. The effect of durian wood biochar (DWB) and corn cob biochar (CCB) doses on (a) corn length; (b) corn cob diameter; (c) dry seed weight; (d) dry water content.

Figure 2e showed that the highest dry weight of seed in acid sulphate soil was obtained from 12 t ha\(^{-1}\) (B4) biochar dose, which increased by 89.3\% for durian wood biochar and 88.6\% for corn cob biochar, compared with the treatment without biochar (B1). Ngongo [28] state that the optimum dose of bamboo biochar on dry weight of seed was 10.44 t ha\(^{-1}\). Bamboo biochar on 10 t ha\(^{-1}\) could increase the growth of corn crops in dryland [29].
4. Conclusion
Biochar treatment significantly affected plant height age of 2nd, 4th, 6th, 8th, 10th and 12th weeks. The longer the age, the higher the corn plant height. The corn cob length, corn cob diameter, dry weight of seed, and the dry water content significantly different in all treatments. The biochar dose significantly affected the corn yields. The corn cob length was (11.20-14.14) cm for DWB treatment and (10.98-114.67) cm for CCB treatment. The diameter of corn cobs was (3.14-3.55) cm for DWB and (3.23-3.67) cm for CCB. The dry weight of seed was (26.77-50, 68) gr for DWB and (27.17-51.23) gr for CCB. The dry water content was (13.17-15.50) % for DWB and (13.24-14.56) % for CCB. The best treatment of biochar in acid sulphate soil was obtained in 12 t ha⁻¹.

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References
[1] International Biochar Initiative 2015 Standardized product definition and product testing guidelines for biochar that is used in soil Version number 2.1
[2] Saletnik B, Zagula G, Bajcar M, Tarapatskyy M, Bobula G and Puchalski C 2019 Biochar as a multifunctional component of the environment-A review Appl. Sci. 9 1139
[3] Timmons D, Lema-Driscoll A and Uddin G 2017 The economics of biochar carbon sequestration in Massachusetts (Boston: University of Massachusetts) p 62
[4] Verma M, Godbout S, Brar S K, Solomatnikova O, Lemay S P and Larouche J P 2012 Biofuels production from biomass by thermochemical conversion technologies Int. J. Chem. Eng., 2012 542426
[5] Tomczyk A, Sokolowska Z and Boguta P 2020 Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects Rev. Environ. Sci. Biotechnol. 19(1) 191–215
[6] Domingues R R, Trrugilho P F, Silva C A, de Melo I C N A, Melo L C A, Magriotis, Z M, Sánchez-Monedero M A 2017 Properties of biochar derived from wood and high-nutrient biomasses with the aim of agronomic and environmental benefits PLoS One 12(5) 1–19
[7] Manickam T, Cornelissen G, Bachmann R T, Ibrahim I Z, Mulder J and Hale S E 2015 Biochar application in Malaysian sandy and acid sulfate soils: Soil amelioration effects and improved crop production over two cropping seasons Sustainability 7 16756–70
[8] Shamshuddin J, Azura A E, Shazana M A R S, Fauziah C I, Panhwar Q A and Naher U A 2014 Properties and management of acid sulfate soils in Southeast Asia for sustainable cultivation of rice, oil palm, and cocoa Advances in Agronomy (Cambridge: Academic Press) chapter 3 pp 91–142
[9] Brewbaker J L 2003 Corn production in the tropics: The Hawaii experience (Manoa: University of Hawaii) p 76
[10] Raihan H S 2000 Pemupukan NPK dan ameliorasi lahan pasang surut sulfat masam berdasarkan nilai uji tanah untuk tanaman jagung J. Ilmu Pertan. 9(1) 20–8
[11] Brantley K E, Savin M C, Brye K R and Longer D E 2015 Pine woodchip biochar Impact on soil nutrient concentrations and corn yield in a silt loam in the Mid-Southern U.S. Agriculture 5 30–47
[12] Uzoma K C, Inoue M, Andry H, Fujimaki H, Zahoor A and Nishihara E 2011 Effect of cow manure biochar on maize productivity under sandy soil condition Soil Use Manag. 27(2) 205–12
[13] Setiawati E, Prijono S, Mardiana D, Prayogo C and Soemarno 2019 Impact of pyrolysis temperature and water quenching on hydrophilicity of biochar derived from durian wood waste Biosci. Res. 16(2) 2047–62
[14] Harter H L 1960 Critical values for Duncan’s New Multiple Range Test Biometrics 16(4) 671–85
[15] Iskandar T and Rofiatin U 2017 Karakteristik biochar berdasarkan jenis biomassa dan parameter proses pyrolysis J. Tek. Kim. 12(1) 28–34
[16] Shafie S T, Mohd.Salleh M, Hang L L, Rahman M, Azlina W and Ghani W A W A k 2012 Effect of pyrolysis temperature on the biochar nutrient and water retention capacity,” J. Purity, Util. React. Environ. 1(6) 323–37
[17] Lehmann J 2007 Bio-energy in the black Front Ecol Env. 5(7) 381–7
[18] Blok C, Regelin I, Hofland-Zijistra J, Streminska M, Evelens B and Bolhuiss P 2016, Perspectives for the use of biochar in horticulture (Netherland: Wageningen UR Greenhouse Horticulture) p 40
[19] Ndruru J I, Nelvia and Adiwirman 2018 Application of biochar and liquid Smoke to the growth of upland rice (Oryza sativa. L) on ultisol medium J. Agroteknologi 9(1) 9–16
[20] Chowdhury Z Z, Karim Z M, Ashraf M A and Khalid K 2016 Influence of carbonization temperature on physicochemical properties of biochar derived from slow pyrolysis of durian wood (Durio zibethinus) sawdust BioResources 11(2) 3356–72
[21] Yang H, Yan R, Chen H, Lee D H and Zheng C 2007 Characteristics of hemicellulose, cellulose and lignin pyrolysis Fuel 86(12–13) 1781–88, 2007
[22] Khodadad C L M, Zimmerman A R, Green S J, Uthandi S, and Foster J S 2010 Taxa-specific changes in soil microbial community composition induced by pyrogenic carbon amendments,” Soil Biol. Biochem 43(2) 385–92
[23] Lehmann J and Joseph S 2012 Biochar for environmental management: Science and technology, 2nd ed (London: Earthscan) p 944
[24] Poletto M and Zattera A J 2013 Materials produced from plant biomass. Part III: Degradation kinetics and hydrogen bonding in lignin Mater. Res. 16(5) 1065–70
[25] Seresmic S I, Zivanov M S, Milosev D S, Vasin J R, Ciric V I, Vasiljevic M B and Vujic N J 2015 Effects of biochar application on morphological traits in maize and soybean Matica Srp. J. Nat. Sci.129 17–25
[26] Alvum-Toll K, Karlsson T and Strom H 2011 Biochar as soil amendment-A comparison between plant materials for biochar production from three regions in Kenya (Sweden: Swedish University of Agricultural Sciences) p 68
[27] Trupiano D, Cocozza C, Baronti S, Amendola C, Vaccari F P, Lustrato G, Lonardo S D, Fantasma F, Tognetti R, Scippa G S 2017 The effects of biochar and its combination with compost on lettuce (Lactuca sativa L.) growth, soil properties, and soil microbial activity and abundance Int. J. Agron. D 3158207
[28] Ngongo P M 2018 Utilization of bamboo biochar andphonska fertilizer on cultivation of maize (Zea mays L. SEAS (Sustainable Environ. Agric. Sci. 2(1) 67–71
[29] Situmeang Y P, Adnyana I M, Subadiyasa I N N and Merit I N 2015 Effect of dose biochar bamboo, compost, and phonska on growth of maize (Zea mays L.) in dryland Int. J. Adv. Sci. Eng. Inf. Technol. 5(6) 433–39