

Improvement of Soil Chemical Properties and Growth of Maize due to Biochar Application on Ultisol

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ABSTRACT

Ultisols have poor soil characteristics, yet biochar is one of the technologies that can be applied as a soil enhancer to improve the soil quality. Biochar has succeeded in improving soil quality, through improving soil physical, chemical, and biological properties. This research aimed to improve the quality of soil chemical properties and growth of maize plant, as well as to find a combination between biochar type and dosage of biochar that is able to improve the chemical properties of Ultisols and/or the growth of maize plant. This research was conducted at the Greenhouse and Soil Science Laboratory, Faculty of Agriculture, University of Lampung. This study used a randomized block design (RBD) arranged in factorial with 3 factors and 3 replications. The first factor was the soil layer (topsoil and subsoil), the second factor was the type of biochar (biochar of cocoa shell and biochar of oil palm shell), and the third factor was the biochar dosage (0, 10%, 20%, and 30% of 10 kg of oven dry weight soil). The results showed that (1) the application of biochar from the cocoa shell and oil palm shell on Ultisols improved some parts of soil chemical properties, namely CEC, organic C, and K_{exc} , (2) application of biochar from the cocoa shell and oil palm shell on Ultisols increased the plant height, the number of leaves, and the dry weight of maize, (3) application of biochar from the cocoa shell at a dosage of 20% was significantly improved CEC of Ultisols (4) application of biochar from the cocoa shell in top soil at a dosage of 30% significantly improved the soil organic C of Ultisol, (5) application of biochar from cacao shell at a dosage of 30% was significantly improved K_{exc} , (6) application of biochar from oil palm shell at a dosage of 10% significantly increased maize plant growth.

Keywords: Biochar, Cation Exchange Capacity (CEC), exchangeable-K, maize, organic-C, Ultisol

ABSTRAK

Ultisols memiliki karakteristik tanah yang buruk. Pemanfaatan *biochar* sebagai bahan pembenah tanah merupakan salah satu teknologi yang dapat diterapkan. *Biochar* telah diketahui dapat memperbaiki produktivitas tanah marginal baik secara fisika, kimia, dan biologi. Penelitian ini bertujuan untuk mempelajari pengaruh *biochar* terhadap perbaikan sifat kimia tanah dan respon tanaman jagung, serta mencari kombinasi jenis *biochar* dan takaran yang berpengaruh secara positif untuk memperbaiki sifat kimia tanah Ultisols dan atau pertumbuhan tanaman jagung. Penelitian ini dilaksanakan di Rumah Kaca dan Laboratorium Ilmu Tanah Fakultas Pertanian Universitas Lampung. Penelitian ini menggunakan Rancangan Acak Kelompok (RAK) yang disusun secara faktorial dengan 3 faktor dan 3 ulangan. Faktor pertama adalah kedalaman lapisan tanah (lapisan *topsoil* dan *subsoil*), faktor kedua adalah jenis *biochar* (*biochar* yang berasal dari kulit buah kakao dan *biochar* yang berasal dari tempurung kelapa sawit), dan faktor ketiga adalah takaran aplikasi *biochar* (0, 10%, 20%, dan 30% dari 10 kg tanah setara berat kering oven). Hasil penelitian menunjukkan bahwa (1) aplikasi *biochar* asal kulit buah kakao dan tempurung kelapa sawit pada tanah Ultisols memperbaiki beberapa sifat kimia tanah seperti KTK tanah, C-organik, dan K-dd tanah, (2) Aplikasi *biochar* asal kulit buah kakao dan tempurung kelapa sawit pada tanah Ultisols meningkatkan tinggi tanaman, jumlah daun, dan bobot kering berangkas tanaman jagung, (3) aplikasi *biochar* yang berasal dari kulit buah kakao dengan takaran 20 % nyata mempebaiki KTK tanah Ultisols, (4) aplikasi *biochar* yang berasal dari kulit buah kakao pada lapisan atas dengan takaran 30 % nyata mempebaiki C-organik tanah Ultisols, (5) aplikasi *biochar* yang berasal dari

kulit buah kakao dengan takaran 30% nyata mempebaiki K-dd tanah Ultisols, (6) aplikasi biochar yang berasal dari tempurung kelapa sawit dengan takaran 10% nyata meningkatkan pertumbuhan tanaman jagung.

Kata kunci: Biochar, C-organik, Kapasitas Tukar Kation (KTK), K-dd, tanaman jagung, Ultisol

INTRODUCTION

Soil is one of the factors that play an important role in agriculture site, because soil is a growing medium and provides nutrients for plants. Agricultural land in Indonesia is dominated by Ultisols. Sumatra has the second highest area of Ultisols after Kalimantan (Prasetyo and Suriadikarta 2006). In terms of soil chemical properties, Ultisols are characterized by soil acidity (pH) accompanied by high Al, Fe, and Mn content; high P adsorption, low cation exchange capacity (CEC), low organic C content and the availability of elements such as N, P, K, Ca, Mg, and Mo are relatively low (Kaya 2009; Yuwono 2009). Therefore, input technology is needed to improve the quality of Ultisols by using soil amendments, such as biochar, which is a soil enhancer that has been known for a long time. The origin material of biochar is derived from agricultural and forestry waste that has undergone incomplete combustion (pyrolysis) in order to obtain charcoal containing activated carbon to be applied to the soil (Nurida *et al.* 2009; Lehmann and Joseph 2009).

The addition of biochar into the soil has been known to improve marginal soils like Ultisols physically, chemically and biologically. Based on the previous research, the addition of biochar to the soil could increase CEC, pH, and availability of some nutrients (Glaser *et al.* 2002; Lehmann *et al.* 2003; Yamato *et al.* 2006; Soemeinaboedhy and Tejowulan 2007; Deenik *et al.* 2009; Baronti *et al.* 2010; Graber *et al.* 2010). In improving soil biology, the presence of biochar in the soil can be used as habitat for fungi and other soil microbes (Santi and Goenadi 2010; Noguera *et al.* 2010; Smith *et al.* 2010; Elad *et al.* 2011). Biochar has the ability to increase water holding capacity at an average of above 45%, so it will be able to prevent the loss of fertilizer due to surface run off and leaching (Nurida *et al.* 2009; Ferizal 2011).

Hunt *et al.* (2010) studied that the maximum application dose for biochar depend on the soil type cultivated plants. Based on research conducted on several plants, biochar applied at a rate between 5% and 20% of the total soil volume showed a positive impact on crop production. In addition, several studies had also shown that the application of low concentrations of biochar were evident in

increasing the growth of some plants (Rondon *et al.* 2007; Zhang *et al.* 2011).

This research aimed to study the effect of biochar on the chemical properties of Ultisols, the growth of maize plants, and to find the combination of types and dosage of biochar that would have a positive effect on improving the chemical properties of the soil and / or the growth of maize plants.

MATERIALS AND METHODS

Research Location

Biochar production was carried out in the Research Station of Indonesian Soil Research Institute in Taman Bogo, East Lampung. Analysis of soil chemical properties and maize plant tissue were carried out at the Soil Science Laboratory of the Faculty of Agriculture, University of Lampung. The pot experiment was conducted at the Greenhouse of the Faculty of Agriculture, University of Lampung.

Biochar Production

The agricultural wastes used as raw materials for biochar were cocoa shell and oil palm shell. The combustion process was carried out in the Research Station of Indonesian Soil Research Institute in Taman Bogo, East Lampung. Combustion was done by using a pyrolysis through incomplete combustion (pyrolysis) with a temperature of about 250-350 °C for approximately 1 hour (Nurida *et al.* 2009). After the combustion process was completed, the resulting biochar was sieved using 2 mm size sieve. The methods of biochar analysis were using standardized by the Indonesian Soil Research Institute (Sulaeman *et al.* 2005). The variables observed were pH, CEC, total N, organic-C, available-P, exchangeable-K, and C/N ratio.

Preparation of Planting Media

The soil samples were using Ultisols that was taken from the Research Station of Indonesian Soil Research Institute in Taman Bogo, East Lampung. Soil samples were taken from two layers, namely the topsoil (0-20 cm) and the subsoil (20-40 cm). The size of polybag was 10 kg. The soil samples were dried, smoothed using a grinder, and 2 mm

sieved. A total of 10 kg soil, equivalent to the oven dry weight, was mixed with biochar according to the dose of each treatment. Biochar was applied before planting. The mixture of soil and biochar was applied by NPK fertilizer as a base fertilizer according to the recommendations, namely urea 1,5 g polybag⁻¹, SP-36 0,5 g polybag⁻¹, and KCl 0,5 g polybag⁻¹. Before being put into a polybags the whole mixture was stirred evenly. After being put into the polybags, about 40% of the volume of soil was added to the water so it approaches the field capacity. The planting medium was then incubated for 2 weeks in a closed state before planting.

Plant Analysis

Each polybag was planted with two seeds of Lambada 1 sweet maize seeds, with a depth of 3 cm planting hole. One week after planting, in each polybag the best growth plants were selected. Plant maintenance was carried out by watering until the soil condition approaches the field capacity. Weed control was done manually, namely by weeding the weeds that grew in polybags. Harvesting was done when the plant reached the maximum vegetative phase (7 weeks after planting). Observation of plant growth parameters started one week after planting. The variables were plant height and number of leaves which were observed every week until 7 weeks after planting. And the supporting variables observed were dry weight of the trunk (7 weeks after planting).

Soil Analysis

The soil samples used for initial analysis had not been treated with biochar. Initial analysis of the soil chemical properties were carried out in the topsoil (0-20 cm) and the subsoil (20-40 cm). The variables observed were Cation Exchange Capacity (CEC) with NH₄OAc method, organic-C with Walkey and Black method, and K_{exc} with NH₄OAc method. While the soil samples used for the final analysis were taken from each polybag, by unpacking the polybags, then compiled from the area around the roots. Soil chemical properties observed in the final soil sample were CEC, organic C, and K_{exc}. The method of soil analysis is using standardized by the Indonesian Soil Research Institute (Sulaeman *et al.* 2005).

Experimental Design and Data Analysis

The experimental design used in this study was a Randomized Block Design. The treatments were arranged in a factorial with three factors and three replications. The first factor was the depth of the soil layer (topsoil 0-20 cm and subsoil 20-40 cm), the second factor was the type of biochar (biochar

derived from the cocoa shell, and biochar derived from the oil palm shell), and the third factor was the application dosage of biochar (0% biochar, 10% biochar, 20% biochar, and 30% biochar from 10 kg of soil).

The data obtained were tested for homogeneity using the Bartlett Test and additivity by the Tukey Test. Those data who passed the test was continued with analysis of variance (F Test), then continued with the Honestly Significant Difference (HSD) Test at the 5% level.

RESULTS AND DISCUSSION

Chemical Properties of Ultisol and Biochar

The results of preliminary analysis of the chemical properties of Ultisols and biochar were presented in Table 1. Based on the criteria for assessment of soil analysis that had been standardized by the Indonesian Soil Research Institute (Sulaeman *et al.* 2005), Ultisols used in this study had acidic soil (pH) reactions, CEC and total-N were low, organic-C was very low as well as P-available and K_{exc}. While the chemical properties of biochar derived from the cocoa shell had an alkaline soil reaction (pH), low CEC, very high total-N, organic-C, available-P as well as exchangeable-K (K_{exc}). The chemical properties of biochar derived from oil palm shell had somewhat alkaline soil reactions, low CEC, very low total-N and organic-C, very high available-P, and moderate K_{exc}.

Based on the results of the analysis, overall biochar derived from the cocoa shell had better chemical properties compared to biochar from palm oil shell. That statement had been revealed by Lehmann and Joseph (2009) and Hunt *et al.* (2010), which stated that the characteristics of the chemical properties and the quality of biochar were determined by the origin material of the biochar.

Effect of Application of Biochar on CEC

The results of the analysis of variance (Table 2) showed that the application of types and dosages of biochar had a significant effect in improving the CEC of Ultisols, while the soil layer had no significant effect. In addition there was a significant interaction between the types and the dosages of biochar on CEC.

Interactions between the types and dosages of biochar are presented in Table 3. It is shown that the treatment that had the highest CEC value was the soil which was applied by biochar from the cocoa shell at a dosage of 20%. While the lowest CEC was on the soil that was applied by biochar from

Table 1. Chemical properties of Ultisol and biochar.

Parameter	Topsoil	Subsoil	Cocoa Shell Biochar	Palm Oil Shell Biochar
pH	4.89	5.37	9.90	7.87
CEC (cmol(+) kg ⁻¹)	5.12	7.91	11.60	10.60
Total-N (%)	0.17	0.15	0.79	0.09
Organic-C (%)	0.99	0.76	5.02	0.92
Available-P (mg kg ⁻¹)	4.33	1.15	22.02	80.54
Exchangeable-K (cmol (+) kg ⁻¹)	0.04	0.03	3.04	0.49
C/N ratio	5.81	5.09	6.33	9.93

Table 2. Analysis of variance summary of CEC content on ultisols due to the application of several types of biochar.

Diversity Source	CEC (cmol(+) kg ⁻¹)	Organic-C (%)	Exchangeable-K (cmol(+) kg ⁻¹)
Soil Layer	ns	*	*
Biochar Types	*	*	*
Dosage	*	*	*
Layer*Biochar Types	ns	ns	ns
Layer*Dosage	ns	ns	ns
Biochar types*Dosage	*	*	ns
Layer*Biochar Types*Dosage	ns	*	*

Note: ns = not significantly different at 5% level of significance, * = significantly at 5 % level of significance

the cocoa shell at a dosage of 0%. The soil that was applied by biochar from cocoa shell had a higher CEC value compared to biochar from oil palm shell, as a result the ability of biochar from oil palm shell to absorb cations was greater than the biochar from the cocoa shell. In addition Nigussie *et al.* (2012) also stated that the porous nature of biochar and the capacity of biochar that can be used as a medium by microorganisms for activity are thought to also play a role in improving soil quality and absorbing

higher nutrients, so that the value of the CEC will also increase.

Effect of Biochar Application on Soil Organic-C

The results of the analysis of variance (Table 2) showed that the application of biochar types, dosages, and soil layers had a significant effect in improving the organic-C of Ultisol. In addition there

Table 3. Effect of interaction between biochar types and dosages on CEC of Ultisol (data were transformed into \sqrt{x}).

Treatment	Cation Exchange Capacity (cmol(+) kg ⁻¹)			
	Without biochar (B0)	10% biochar (B1)	20% biochar (B2)	30% biochar (B3)
Biochar from cocoa shell	0.79 c (A)	0.98 ab (A)	1.00 a (A)	0.99 ab (A)
Biochar from oil palm shell	0.84 a (A)	0.85 a (A)	0.82 a (A)	0.87 a (A)

HSD 5% = 0.18

Note: The numbers followed by the same letters in the same column or row are not significantly different from the HSD test at 5% level. Lowercase letters are read horizontally, capital letters are read vertically.

Table 4. Effect of interaction between biochar types and dosages on organic-C content in Ultisol.

Treatments		Organic C (g kg ⁻¹)			
Biochar Types	Horizons	Without biochar (B0)	10% biochar (B1)	20% biochar (B2)	30% biochar (B3)
Biochar from cocoa shell	Topsoil Layer (0-20 cm)	0.61 c (A)	0.98 b (A)	1.14 b (A)	1.48 a (A)
	Subsoil Layer (20-40 cm)	0.71 b (A)	0.60 b (A)	0.74 b (A)	1.09a (B)
Biochar from oil palm shell	Topsoil Layer (0-20 cm)	0.87 a (A)	0.54 b (A)	0.64 a (A)	0.78 a (A)
	Subsoil Layer (20-40 cm)	0.43 a (B)	0.57 a (A)	0.59 a (A)	0.53 a (A)

HSD 5% = 0.31

Note: The numbers followed by the same letters in the same column or row are not significantly different from the HSD test at 5% level. Lowercase letters are read horizontally, capital letters in are read vertically.

were significant interactions between the types of biochar, dosages, and soil layers on soil organic-C.

Interactions between biochar types, dosages, and layers are presented in Table 4. In general, the higher the dosage of biochar application, the higher the soil organic-C content. This is allegedly because the organic-C content in biochar was already high, therefore the presence of biochar indirectly contributes a number of carbon into the soil. The

result showed that the highest soil organic-C content (1.48%) was on the topsoil applied with biochar from cocoa shell at a dosage of 30%. This might be due to the carbon content in the biochar from the cocoa shells were already very high (5.02%). Whereas the lowest organic-C (0.43%) was in the subsoil which was applied by biochar from the oil palm shell with a dosage of 0%.

Table 5. Effect of interaction between biochar types and Kexc on ultisols.

Treatments	Kexc (cmol(+) kg ⁻¹)			
	Without biochar (B0)	10% biochar (B1)	20% biochar (B2)	30% biochar (B3)
Biochar from cocoa shell	0.29 c (A)	1.29 b (A)	1.50 a (A)	1.61 a (A)
Biochar from oil palm shell	0.28 c (A)	0.35 c (B)	0.47 ab (B)	0.52 a (B)

HSD 5% = 0.31

Note: The numbers followed by the same letters in the same column or row are not significantly different from the HSD test at 5% level. Lowercase letters are read horizontally, capital letters are read vertically.

Table 6. F-test summary of maize plant growth.

Diversity Source	Plant height (cm)	Number of leaves	Dry weight (g)
Layer	ns	ns	ns
Biochar Types	*	*	*
Dosage	*	ns	*
Layer*Biochar Types	ns	ns	ns
Layer*Dosage	ns	ns	ns
Biochar Types*Dosage	ns	ns	*
Layer*Biochar Types*Dosage	ns	ns	ns

Note: ns = not significantly different at 5% level of significance, * = significantly at 5 % level of significance

Table 7. Effect of biochar types on plant height, number of leaves, and dry weight of maize plant.

Biochar measurement	Plant height (cm)	Number of leaves	Dry weight (g)
Biochar from cocoa shell	72.82 b	5.46 b	2.84 b
Biochar from oil palm shell	124.27 a	7.21 a	8.03 a
HSD 5%	15.96	0.89	2.69

Note: The number followed by the same letter in the same column is not significantly different from the HSD test at the 5% level.

Table 8. Effect of biochar dosages on plant height and dry weight of maize plant.

Biochar dosage	Plant height (cm)	Dry weight (g)
0%	95.91 ab	3.46 b
10%	123.52 a	9.25 a
20%	97.38 ab	5.17 ab
30%	77.37 b	3.84 b
HSD 5%	30.11	5.09

Note: The numbers followed by the same letters in the same column are not significantly different from the HSD test at 5% level.

Effect of Biochar Application on Exchangeable-K

The results of the analysis of variance (Table 2) showed that the application of biochar types, dosages, and soil layers had a significant effect in improving the K_{exc} on ultisols. In addition there were significant interactions between the types of biochar and the content of K_{exc} in soil.

Interactions between biochar types and quantities are presented in Table 5. The higher the biochar dosage applied to the soil, the higher the measured K_{exc} . This was presumably due to the high K content of biochar, the alkaline condition of biochar, and the CEC content of biochar which was already high. The highest K_{exc} was in the soil that was applied by biochar from cocoa shell at a dosage of 30%. While the lowest K_{exc} was in the subsoil which was applied by biochar from the cocoa shell at a dosage of 0%.

Effect of Application of Several Biochar Types on the Growth of Maize

The results of the analysis of plant height, number of leaves, and dry weight are presented in Table 6. Based on the research data, the application of biochar types increased the height, the number of leaves, and the stall dry weight of maize plants. While the actual dosage increased the plant height and the dry weight of the maize plant.

The effect of biochar types on the plant height and the dry weight of maize plants are presented in Tables 7 and 8. Based on Table 7 shows that biochar from oil palm shells was better in increasing plant growth compared to biochar derived from cocoa shell. Table 8 shows that the plant height, the 10% biochar dosage was significantly different from the 30% dosage, but it was not different from the biochar dosages of 0% and 20%. Whereas the dry weight of maize plants using 10% biochar application was different from 0% and 30%, but it was not different from 20%. This shows that the provision of biochar with a low dosage had an effect on the plant height and the dry weight of maize plants.

CONCLUSIONS

Application of biochar from cocoa shell and oil palm shells on Ultisol improves some chemical properties of soil such as CEC, organic-C, and K_{exc} . Application of biochar from cocoa shells and oil palm shells on Ultisol increased the plant height, the number of leaves, and the dry weight of maize plants. Application of biochar from the cocoa shell at a dosage of 20% significantly increased the CEC on Ultisol. Application of biochar derived from the cocoa shell in top soil at a rate of 30 % significantly improves the soil organic-C on Ultisol. Application of biochar from the cocoa shell at a dosage of 30% significantly increased the K_{exc} on Ultisol. Application

of biochar from oil palm shell at a dosage of 10% significantly increased the growth of maize plant.

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REFERENCES

- Baronti S, G Alberti, GD Vedove, FD Gennaro, G Fellet, L Genesio, F Miglietta, A Peressotti, and FP Vaccari. 2010. The biochar option to improve plant yields: first result from some field and pot experiments in Italy. *Ital J Agron* 5: 3-11.
- Deenik JL, AT McClellan and G Uehara. 2009. Biochar volatile matter content effects on plant growth and nitrogen transformations in a tropical soil. *Western Nutrient Management Conference*. Vol 8. Salt Lake City, UT.
- Elad Y, E Cytryn, YM Harel, B Lew and ER Geabber. 2011. The biochar effect: plant resistance to biotic stresses. *Phytopathol Mediterr* 50: 335-349.
- Ferizal M. 2011. Arang hayati (Biochar) sebagai bahan pembenah tanah. Balai Pengkajian Teknologi Pertanian Aceh. Edisi Khusus Penas XIII, 22 Juni 2011. (in Indonesian).
- Glaser B, J Lehmann and W Zech. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review. *Biol Fertil Soils* 35: 219-230.
- Graber ER, YM Harel, M Kolton, E Cytryn, A Silber, DR David, L Tsechansky, M Borenshtein and Y Elad. 2010. Biochar impact on development and productivity of pepper and tomato grown in fertigated soilless media. *Plant Soil* 337: 481-496.
- Hunt J, M Du Ponte, D Sato and A Kawabata. 2010. The basic of biochar: A natural soil amendment. Soil and Crop Management. College of Tropical Agriculture and Human Resources. University of Hawai'i Manoa.
- Kaya E. 2009. Ketersediaan fosfat, serapan fosfat, dan hasil tanaman jagung (*Zea mays* L.) akibat pemberian bokashi ela sagu dengan pupuk fosfat pada Ultisols. *J Ilmu Tanah Lingk* 9: 30-36. (in Indonesian).
- Lehmann J and S Joseph. 2009. Biochar Environmental management. Earthscan. London. 416p.
- Lehmann J, JP Da Silva Jr, C Steiner, T Nehls, W Zech and B Glaser. 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant Soil* 249: 343-357.
- Nigussie A, E Kissi, M Misganaw and G Ambaw. 2012. Effect of biochar application on soil properties and nutrient uptake of lettuces (*Lactuca sativa*) grown in chromium polluted soils. *Am-Eur J Agric Environ Sci* 12: 369-376.
- Noguera D, M Rondon, KM Laossi, V Hoyos, P Lavelle, MHCD Carvalho and S Barot. 2010. Contrasted effect of biochar and earthworms on rice growth and resource allocation in different soils. *Soil Biol Biochem* 42: 1017-1027.
- Nurida NL, Ai Dariah and A Rachman. 2009. Kualitas limbah pertanian sebagai bahan baku pembenah tanah berupa biochar untuk rehabilitasi lahan. Balai Penelitian Tanah. Bogor. (in Indonesian).
- Prasetyo BH and DA Suriadikarta. 2006. Karakteristik, potensi, dan teknologi pengelolaan tanah ultisol untuk pengembangan pertanian lahan kering di Indonesia. *J Litbang Pertanian* 25: 39-47.
- Rondon MA, J Lehmann, J Ramirez and M Hurtado. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with bio-char additions. *Biol Fertil Soils* 43: 699-708.
- Santi LP and DH Goenadi. 2010. Pemanfaatan biochar sebagai pembawa mikroba untuk pemantap agregat tanah Ultisol dari Taman Bogo-Lampung. *Menara Perkebunan* 78: 52-60. (in Indonesian).
- Smith JL, HP Collins and VL Bailey. 2010. The effect of young biochar on soil respiration. *Soil Biol Biochem* 42: 2345-2347.
- Soemeinaboedhy IN and RS Tejawulan. 2007. Pemanfaatan berbagai macam arang sebagai sumber unsur hara P dan K serta sebagai pembenah tanah. *Agroteksos* 17: 114-122. (in Indonesian).
- Sulaeman, Suparto and Eviati. 2005. Petunjuk Teknis Analisis Kimia Tanah, Tanaman, Air, dan Pupuk. Balai Penelitian Tanah. Bogor. 136 hlm. (in Indonesian).
- Yamato M, Y Okimori, IF Wibowo, S Anshori and M Ogawa. 2006. Effects of the application of charred bark of *acacia mangium* on the yield maize, cowpea and peanut, and soil chemical properties in South Sumatra, Indonesia. *Soil Sci Plant Nutr* 52: 489-495.
- Yuwono NW. 2009. Membangun kesuburan tanah di lahan marginal. *J Ilmu Tanah Lingk* 9: 137-141. (in Indonesian).
- Zhang A, Y Liu, G Pan, Q Hussain, L Li, J Zheng and X Zhang. 2012. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from central china plain. *Plant Soil* 351: 263-275.