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Effect of Biochar Derived from Coffee Sludge on Growth of Chinese Cabbage (*Brassica campestris* L. ssp. *pekinensis*) in Field Soil and Bed Soil

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Biochar is the carbon solid produced through the pyrolysis of biomass from organic sources such as agricultural waste, animal manure, and sludge under limited or anaerobic conditions. It is known to function as a soil amendment, affecting water and nutrient retention, soil acidification, and active growth of soil microorganisms. This experiment was conducted to evaluate the application of biochar on the growth characteristics of Chinese cabbage at Chungnam National University in Daejeon, Korea from December 28, 2016 to February 22, 2017. Coffee sludge was used to produce biochar through pyrolysis, which was then applied at 0%, 2%, and 5% to field soil and bed soil. In field soil, the Chinese cabbage with 5% treatment of coffee sludge biochar had the highest fresh weight (116.46 ± 1.3 g/plant) and as the content of biochar increased, the number of leaves that appeared also increased. In bed soil, the Chinese cabbage with 2% coffee sludge biochar treatment had the highest fresh weight (209.35 ± 13.8 g/plant). Compared to the control, biochar treatments resulted in increased number of leaves, leaf length, and leaf width. The organic matter in field soil under 5% coffee sludge biochar treatment was 7.1 ± 0.44%, whereas it was 1.0 ± 0.14% in the control. The organic matter in bed soil under 5% coffee sludge biochar treatment was 31.8 ± 5.86%, whereas it was 25.9 ± 6.00% in the control. An increase in the total nitrogen of both field soil and bed soil was observed when the biochar content increased. Chinese cabbage grew better in bed soil with coffee sludge biochar than in field soil because of the optimal pH conditions. Our results support the application of biochar for increased growth of Chinese cabbage, particularly in bed soil.

Key words: Biochar, Coffee sludge, Chinese cabbage, Bed soil

INTRODUCTION

The soil in Korea is acidic and has a low cation exchange capacity (CEC), because it is composed of the acidic weathering products of granite and granite gneiss found in about two–thirds of the country (Han *et al.*, 2016). These factors and the use of large amounts of chemical fertilizers have resulted in degeneration of the physical properties of the soil and other adverse effects such as acidification and soil salinity (Lee *et al.*, 2016). Additionally, soil loss caused by heavy rain in the summertime has resulted in low soil fertility (Yoon, 2011). Therefore, application of a soil amendment that aims to improve the chemical, physical, and biological properties of soil along with soil nutrient availability is urgent. In these circumstances, biochar, which semi–permanently saves the carbon in the soil through sequestration is reported to be an effective soil amendment (Oh *et al.*, 2017; Woo, 2013). Further, since biochar has a stable aromatic ring structure that is not decomposed by soil microorganisms or environmental factors, its use in soil amendment can ensure long–term soil management (Choi, 2012).

Biochar is the carbon solid produced through the pyrolysis of biomass containing organic waste such as agricultural waste, animal manure, and sludge under limited or anaerobic conditions. It is currently utilized for the improvement of soil, mitigation of global warming, and remediation of heavy metal polluted soil. When used for soil improvement, biochar can increase the productivity of crops by improving soil acidity, water and nutrient retention capacity, and air permeability and active growth of soil microorganism (Novak *et al.*, 2009; Spokas *et al.*, 2009; Atkinson *et al.*, 2010; Kwapinski, 2010; Choi, 2012; Gnag and Yoo, 2012; Woo, 2013). When used for mitigation of global warming, biochar has been reported to reduce N_2O emissions by up to 15% based on the maximum value and semi–permanently save the carbon in the soil (Yanai *et al.*, 2007). Biochar is used to remediate soil polluted by heavy metals such as Cu and Cd because of its high specific surface area (Kim *et al.*, 2012; Koh *et al.*, 2016).

It is advantageous to select a source of biomass readily available in the surrounding environment for the mass–production of biochar. Approximately 9,500 units of coffee shops were recorded in Korea in 2012, and the discarded coffee sludge at 20 kg per day per shop results in environmental pollution. This means 700,000t of domestic waste per shop annually (Ha, 2015). This further leads to serious economic losses, with 10billion won spent to handle this waste (WIKITREE, 2015). In Korea, coffee sludge is studied not only as a bulking agent in aerobic composting of wastewater sludge by using bene-

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ficial microorganisms (Ha, 2015) but also as biochar to improve acidic soil (Choi, 2012) and stabilize heavy metals (Kim *et al*., 2012).

This study aims to investigate the properties of biochar derived from discarded coffee sludge as a soil amendment, as well as its effect on the growth characteristics of Chinese cabbage in field soil and bed soil through pot trials in a greenhouse.

MATERIALS AND METHODS

2.1 Materials

2.1.1 Medium

This experiment was conducted at a greenhouse of Chungnam National University in Daejeon, Korea, from December 28, 2016 to February 22, 2017. The crop used this test was Chinese cabbage (Daewon, Dongwon Nongsan. Co., Yongin, Korea). The field soil was obtained from a research farm of Chungnam National University; samples were taken at approximately 10 cm from the surface and filtered using a 2 mm sieve. The bed soil (High, Punong. Co., Kyoungju, Korea) was composed of 7% zeolite, 7% perlite, 3% vermiculite, 68% coco peat, 14.73% peat moss, 0.243% fertilizer, 0.004% wetting agent, and 0.024% pH regulator. The field soil sample was collected at a depth of 0–10 cm. It was found to be acidic and relatively low in organic matter (Table 1).

2.1.2 Generation of Biochar

The biochar used in this experiment was composed of coffee sludge obtained from coffee shops, and its effect as a soil amendment was investigated. The coffee sludge was dried in an oven for 48 hours at 70°C to remove moisture, and sealed in a container with aluminum foil to prevent the flow of oxygen. It was pyrolyzed at 500°C for 2 hours in a muffle furnace (1100 Box Frunace, LindBerg/Blue M, Thermo Scientific Inc., USA).

2.2 Treatments

Treatments were set up in Wagner pots (1/5000 a, field soil) and in pots (bed soil) of 16.5 cm height and 20 cm diameter at the top and 13.5 cm diameter at the base. Treatment plots of biochar in this experiment were composed of field soil and bed soil at mass ratios of 0%, 2%, and 5%. The trial pots were arranged in a randomized complete block design with three treatments consisting of five replications for Chinese cabbage. The pots were randomly rotated each day to a different position within the block for the duration of the trial. Each pot was provided with 0.15 L of water, one to two times per day as required depending on the prevailing weather conditions. The amount of applied N–P_2O_5–K_2O fertilizer was 21.5–7.8–19.8 kg/10 a based on Recommendation of the amount of fertilizer for crops (RDA, 2010). Direct seeding was conducted with three seeds per pot and weeded when main leaves of Chinese cabbage numbered two or three.

2.3 Methods

2.3.1 Growth Characteristics

Observations of plant height, number of leaves, leaf length, leaf width, head height, head girth, fresh weight (shoot, root), and dry weight (shoot, root) of Chinese cabbage (*Brassica campestris* L. ssp. *pekinensis*) were recorded based on the Research and Analysis Criteria for crops (RDA, 2012). Each investigation item was recorded after harvest. Leaf length was measured from the collar line to the tip of the longest leaf, and leaf width was assessed at the widest region of the leaf. The number of leaves was determined by the total number of leaves that were more than 1 cm. Dry weight (shoot, root) was determined using a drying oven for at least 24 hours at 70°C. Chlorophyll was measured using a MINOLTA Chlorophyll meter (SPAD–502, Japan) for the leaves positioned in the center.

2.3.2 Analysis

Analysis of field soil, bed soil, and biochar samples was conducted using the method for analysis of soil and manure (Gyeonggi–do Agricultural Research & Extension Service). Soil samples were collected during the experimental set up and were air–dried for at least 24 h and then filtered using a 2 mm sieve. Bed soil samples were also collected during the experimental set up and were air–dried. The yield of biochar was decided by measuring the weight of biochar before and after pyrolysis. The pH and electrical conductivity (EC) were measured by using a pH meter and EC meter (ORION Versa Star Pro, Thermo Scientific Inc., USA) through electrochemical analysis. The organic matter (OM) and total nitrogen (T–N) were determined using a CN analyzer (Eager 300, Thermo Scientific Inc., USA), and available phosphate was measured using a UV–VIS spectrophotometer (Evolution 300, Thermo Scientific Inc., USA) by using the Lancaster method. The exchangeable cations (K, Ca, Mg) were analyzed using inductively coupled plasma optical emission spectrometry (ICP–OES, GBC Scientific, Australia) after leaching by using 1N NH_4OA_C solution calibrated to pH 7.0.

Table 1. Chemical properties of the field soil and bed soil

Sample	pH	EC	OM	T–N	C/N	Avail. P_2O_5 [a)]	Ex. Cations [b)]	
	(1:5)	(dS m^{-1})	(%)				Ca	Mg
Field soil	6.1	0.43	0.9	0.06	9	217	0.53	0.14
Bed soil	6.1	5.48	23.1	0.41	33	1750	1.41	0.84

[a)] Unit, Field soil: mg kg^{-1}, bed soil: mg L^{-1}. [b)] Unit, Field soil: $cmol^+$ kg^{-1}, bed soil: $cmol^+$ L^{-1}.

RESULTS AND DISCUSSION

3.1. Chemical Properties of Biochar

The chemical properties of biochar derived from coffee sludge used for this experiment are shown in Table 2. The pH and EC of coffee sludge biochar were, respectively, 10.0 and 10.9 dS m^{-1}. The alkaline pH of biochar is the result of alkaline salt separated from the organic matter of biomass during pyrolysis (Ahmad *et al.*, 2012). Further, the EC is judged to be caused by concentrated various salts within the ash due to loss of volatile substances through pyrolysis (Cantrell, 2012). Additional properties include 134.9% organic matter, 4.4% total nitrogen, 3992 mg kg^{-1} available phosphate, and exchangeable K, Ca, and Mg.

3.2. Growth Characteristics

3.2.1. Chlorophyll and Nitrate

The chlorophyll and nitrate contents according to the application of coffee sludge biochar in field soil and bed soil collected 57 days after sowing are shown in Table 3. In both field soil and bed soil, as the amounts of coffee sludge biochar applied increased, the chlorophyll and nitrate contents tended to decrease. The chlorophyll content in 5% coffee sludge biochar (CSB 5%) in field soil (44.16 ± 3.53 SPAD) was reduced by 17% compared to that in the control (53.32 ± 0.22 SPAD). In bed soil, chlorophyll in the CSB 5% (41.40 ± 5.32 SPAD) decreased by 16% compared to that in the control (49.28 ± 3.53 SPAD). Additionally, the nitrate content in CSB 5% in field soil (2267 ± 252 ppm) decreased by 57% and in the bed soil (4167 ± 513 ppm) decreased by 24% compared to that in the control (5267 ± 551 ppm and 5500 ± 2100 ppm, respectively). These results confirm that the application of coffee sludge in Chinese cabbage cultivation is proportional to its effects on chlorophyll and nitrate contents (Hong *et al.*, 2001).

3.2.2. Growth Characteristics of Chinese Cabbage

The growth characteristics of Chinese cabbage according to the application of coffee sludge biochar in field soil and bed soil 57 days after sowing are shown in Tables (4, 5) and Fig. (1, 2). In field soil, the highest shoot fresh weight (116.46 ± 1.3 g $plant^{-1}$) was observed in CSB 5%, and shoot fresh weight increased by 9% compared to that in the control (105.84 ± 12.2 g $plant^{-1}$). In addition, the number of leaves tended to increase with application of increasing amounts of coffee sludge biochar. In bed soil, the highest shoot fresh weight (209.35 ± 13.8 g $plant^{-1}$) was observed in CSB 2%, and shoot fresh weight increased by 4% compared to that in the control (200.87 ± 41.1 g $plant^{-1}$). Additionally, the

Table 2. Chemical properties of coffee sludge biochar

pH (1:5)	EC (ds m^{-1})	Element content (%)		C/N	OM	Avail. P_2O_5 (mg kg^{-1})	Ex. cations (cmol kg^{-1})	
		C	N				Ca	Mg
10.0	10.9	78.3	4.4	18	134.9	3992	0.3	0.3

Table 3. The chlorophyll and nitrate contents in Chinese cabbage according to the application of coffee sludge biochar

Treatments	Soil		Bed soil	
	Chlorophyll (SPAD)	Nitrate (ppm)	Chlorophyll (SPAD)	Nitrate (ppm)
Control	53.32±0.22	5267±551	49.28±3.53	5500±2100
Coffee sludge biochar 2%	50.27±2.63	3067±351	43.91±3.33	4700±656
Coffee sludge biochar 5%	44.16±3.53	2267±252	41.40±5.32	4167±513

Abbreviations: CSB, coffee sludge biochar

Table 4. Growth characteristics of Chinese cabbage according to the application of coffee sludge biochar in field soil

Treatments	Shoot		Root		leaf			Head	
	fresh weight	dry weight	fresh weight	dry weight	number	length	width	height	girth
	(g $plant^{-1}$)		(g $plant^{-1}$)		(per plant)	(cm)		(cm)	
Control	105.84±12.2	7.53±0.8	3.62±0.4	0.43±0.1	24.67±2.9	22.91±1.0	12.48±1.2	22.00±1.5	31.00±1.5
CSB 2%	104.29±11.4	7.38±0.9	5.87±0.8	0.58±0.1	25.67±1.5	20.93±0.4	11.49±0.4	19.33±0.8	33.70±0.9
CSB 5%	116.46±1.3	9.56±3.6	7.20±3.2	0.69±0.4	27.33±2.1	20.89±1.5	11.39±0.4	19.37±2.0	34.10±0.7

Table 5. Growth characteristics of Chinese cabbage according to the application of coffee sludge biochar in bed soil

Treatments	Shoot		Root		leaf			Head	
	fresh weight	dry weight	fresh weight	dry weight	number	length	width	height	girth
	(g plant^{-1})		(g plant^{-1})		(per plant)	(cm)		(cm)	
Control	200.87±41.1	10.17±2.3	5.36±0.6	0.58±0.1	32.33±3.2	25.19±1.6	14.82±1.5	24.30±1.2	43.50±3.5
CSB 2%	209.35±13.8	11.62±0.7	6.75±0.8	0.84±0.1	32.67±3.2	27.04±1.4	15.68±0.6	26.43±0.8	40.33±0.8
CSB 5%	188.99±12.6	10.68±1.2	7.22±2.1	0.81±0.1	32.67±2.3	26.54±1.1	15.54±0.6	25.50±2.0	37.63±3.1

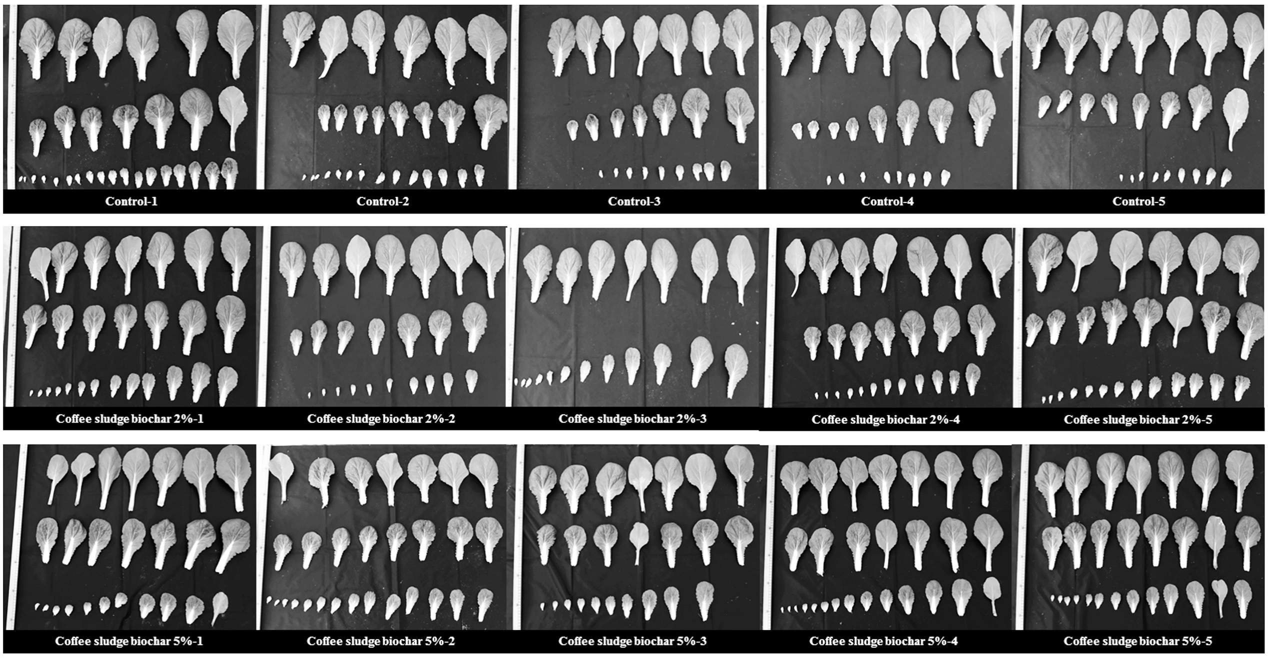

Fig. 1. Growth characteristics of Chinese cabbage according to the application of coffee sludge biochar in field soil.

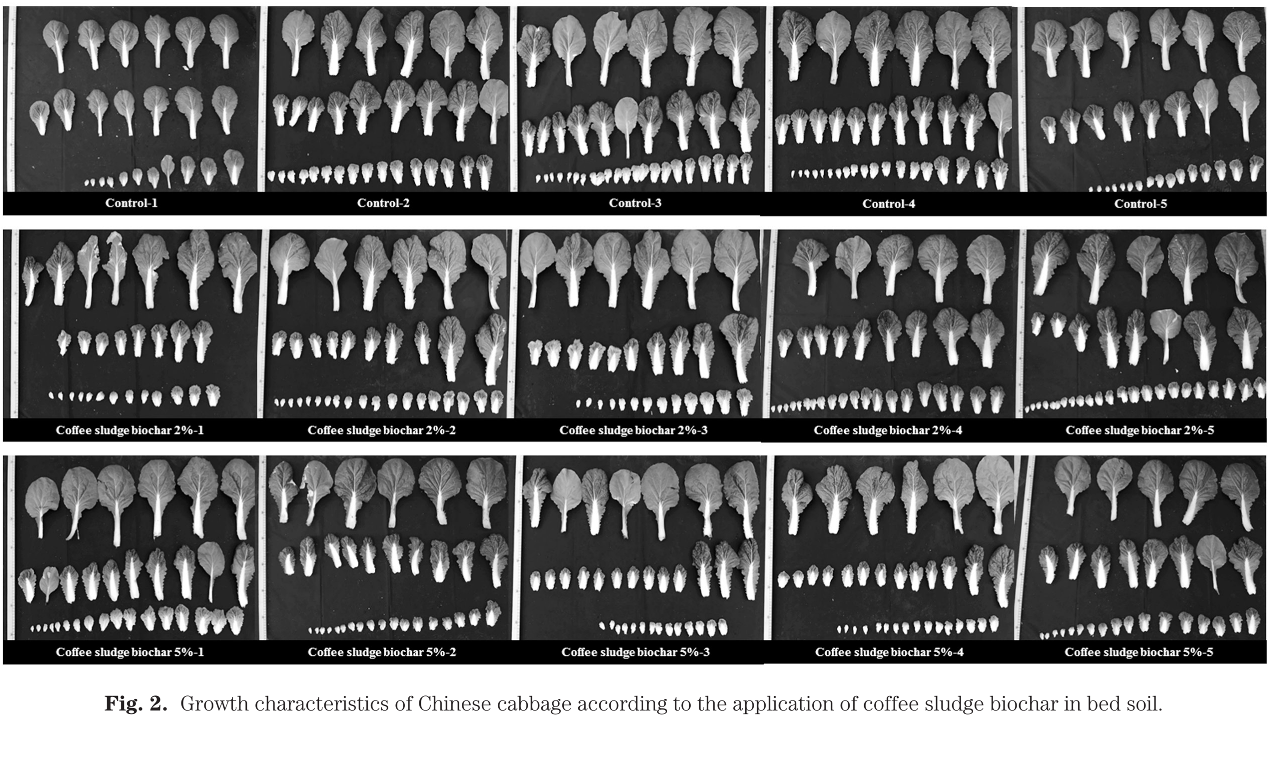

Fig. 2. Growth characteristics of Chinese cabbage according to the application of coffee sludge biochar in bed soil.

number of leaves, leaf length, and leaf width in biochar treatments was more than those of the control. It should be noted that Chinese cabbage in biochar treatments had more water content than that in the control based on the differences in shoot fresh and dry weights because of biochar characteristics such as high specific surface area and pore volume. In addition, the root fresh weight in both field soil and bed soil tended to increase with application of increasing amounts of biochar. This was considered to be caused by an increase in the permeability of roots promoted by the biochar characteristics explained above. The growth characteristics of Chinese cabbage such as shoot fresh weight, number of leaves, leaf length, leaf width, and head height was higher in bed soil than in field soil. This outcome was achieved by the optimal pH levels (6.0–6.5) for the growth of Chinese cabbage in bed soil due to the applied coffee sludge biochar. From these results, it is clear that biochar application improves the growth of Chinese cabbage, particularly in bed soil.

3.3. Chemical Properties of Field Soil and Bed soil

The chemical properties of field soil and bed soil according to the application of coffee sludge biochar are shown in Tables 6 and 7. The pH of field soil in CSB 2% and CSB 5% treatments was 7.1 and 7.8, respectively, which were higher than that of the control (pH 6.0) and exceeded the optimal pH for Chinese cabbage (6.0–6.5). The pH of bed soil in CSB 2% and CSB 5% treatments was 6.4 and 6.5, respectively, whereas that of the control was 6.0. Thus, application of coffee sludge biochar can improve soil acidity, as well as lower the heavy metal contents in soil, thereby regulating their uptake by plants (Lim *et al.*, 2015, Koh *et al.*, 2016). In addition, coffee sludge biochar can be used for consistent management of the soil because biochar has as a stable aromatic ring structure (Choi, 2012). A tendency for the EC to increase was noted in field soil and bed soil treated with coffee sludge biochar compared to the control. Nevertheless, the EC value was lower than the value (2.0dS m^{-1}) that negatively affects the growth of Chinese cabbage. The available phosphate in coffee sludge biochar treatments in both field soil and bed soil was higher than that in the control. As coffee sludge biochar absorbs large amounts of phosphorous comparison to that by general organic matter, it contributes to a more favorable role when crops absorb phosphorus. (Woo, 2013). The organic matter and total nitrogen contents in both field soil and bed soil treated with coffee sludge biochar were higher than those in the control and were within the appropriate standard for cultivation of Chinese cabbage. Soils with low organic matter not only have low nutrient holding capacity but can also cause growth disorders through the harmful action of heavy metal ions. The application of coffee sludge biochar is a possible solution, because it can maintain the optimal organic matter for growing conditions. The cation exchange capacity is expressed as a figure of how fine particles of soil have a negative charge. The fine particles of soil are called soil colloids and these have a negative charge whereas, nutrient components needed to grow crops have a positive charge. Therefore, these tend to be bound with each other. In other words, the high cation exchange capacity means that the ability to retain the nutrients that crops can use is high. The exchangeable cations that have important mean of cation exchange capacity are shown Table 6 and 7. The exchangeable cation in coffee sludge biochar treatments in both field soil and bed soil was slightly decreased compared to control but it didnangeable a significant difference. The changeable calcium content in coffee sludge biochar treatments in field soil was only about 8% (0.47–0.48 $cmol^+ kg^{-1}$) of optimal figure (5–7 $cmol^+ kg^{-1}$). Also, the changeable magnesium content in coffee sludge biochar treatments in field soil was only about 7% (0.13 cmol kg^{-1}) of optimal figure (1.5–2.5 $cmol^+ kg^{-1}$).

Table 6. Chemical properties of field soil after harvesting Chinese cabbage

Treatments	pH (1:5)	EC (dS m^{-1})	OM	T–N	C/N	Avail. P_2O_5 (mg kg^{-1})	Ex. cations ($cmol^+ kg^{-1}$)	
			(%)				Ca	Mg
Control	6.0±0.13	0.38±0.06	1.0±0.14	0.1±0.01	9±0.50	244±21.72	0.55±0.01	0.14±0.02
CSB 2%	7.1±0.16	0.44±0.11	3.7±0.56	0.2±0.02	14±0.19	386±74.98	0.48±0.01	0.13±0.01
CSB 5%	7.8±0.05	0.45±0.02	7.1±0.44	0.3±0.02	15±0.82	444±51.89	0.47±0.02	0.13±0.01

Table 7. Chemical properties of bed soil after harvesting Chinese cabbage

Treatments	pH (1:5)	EC (dS m^{-1})	OM	T–N	C/N	Avail. P_2O_5 (mg L^{-1})	Ex. cations ($cmol^+ kg^{-1}$)	
			(%)				Ca	Mg
Control	6.0±0.46	1.25±0.05	25.9±6.00	0.4±0.08	36±2.07	1171±376.90	2.06±0.31	1.11±0.13
CSB 2%	6.4±0.06	1.74±0.27	26.1±4.72	0.5±0.06	34±2.28	1243±221.13	1.87±0.21	1.04±0.14
CSB 5%	6.5±0.19	1.81±0.07	31.8±5.86	0.6±0.11	31±4.26	1329±250.73	1.85±0.04	1.04±0.03

CONCLUSIONS

This experiment was conducted at a greenhouse of Chungnam National University in Daejeon, Korea, from December 28, 2016 to February 22, 2017, to investigate the properties of biochar derived from coffee sludge, a discarded domestic waste amounting to 700,000 t per year. The biochar was applied as a soil amendment and the growth characteristics of Chinese cabbage in field soil and bed soil were evaluated through pot trials in a greenhouse.

1. In both field soil and bed soil, the chlorophyll and nitrate contents tended to decrease with increase in the amounts of coffee sludge biochar applied.
2. In field soil, the highest shoot fresh weight (116.46 ± 1.3 g plant^{-1}) of Chinese cabbage was observed in 5% coffee sludge biochar, and shoot fresh weight increased by 9% compared to that in the control (105.84 ± 12.2g plant^{-1}). In bed soil, the highest shoot fresh weight 209.35 ± 13.8 g plant^{-1}) of Chinese cabbage was observed in 2% coffee sludge biochar, and shoot fresh weight increased by 4% compared to that in the control (200.87 ± 41.1 g plant^{-1}).
3. The growth characteristics of Chinese cabbage such as shoot fresh weight, number of leaves, leaf length, leaf width, and head height was more favorable in bed soil than in field soil because of attaining the optimal pH levels (6.0–6.5) required for the growth of Chinese cabbage by the addition of coffee sludge biochar.
4. The pH in both field soil and bed soil treated with coffee sludge biochar was higher than that in the control. This result supports the finding that application of coffee sludge biochar can improve acidic growing condition by increasing the pH of field soil and bed soil, as well as lowering the heavy metal content in soil, thereby regulating heavy metal uptake by plants.
5. The EC in field soil and bed soil treated with coffee sludge biochar tended to increase compared with the EC in the control. Nevertheless, the EC values were lower than the value (2.0 dS m^{-1}) that is deleterious to the growth of Chinese cabbage.
6. The available phosphate, organic matter, and total nitrogen in both field soil and bed soil treated with coffee sludge biochar were higher than those in the control.
7. The exchangeable cation in coffee sludge biochar treatments in both field soil and bed soil was slightly decreased compared to control but it didn't shown a significant difference.

AUTHOR CONTRIBUTIONS

Hyeon–Ji SONG, Jae–Han LEE, Su–Hun KIM, and Ho–Cheol LEE carried out analysis and interpretation of data. Yoshiyuki SHINOGI verified the data. Taek–Keun OH supervised the project and wrote the paper. All authors commented on the manuscript.

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