

Effect of Bead-form Biochar as Soil Amendment

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院

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Effect of Bead-form Biochar as Soil Amendment

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Biochar is a solid carbonaceous material that is produced by pyrolyzing biomass under limited oxygen conditions and has been reported to increase soil productivity, absorb pollutants, and reduce greenhouse gasses. The aim of the present study was to evaluate the application of bead-form biochar (BFB) on the growth of pepper (*Capsicum annuum* L.) plants. The wood-waste biochar used in the present study was pyrolyzed at 300°C for 3 h under limited oxygen conditions and processed into beads. Pepper plants were transplanted into pots that contained soil amended with 0, 2, or 5% (w/w) BFB and were grown in a greenhouse for 77 d. The pepper plants grown in 2% BFB were the tallest (93.3 cm) and heaviest (63.0 g), whereas those grown in 5% BFB were the shortest (59.6 cm) and lightest (32.6 g). BFB treatment also affected the chemical properties of the soil, with electric conductivity, available P₂O₅, total carbon, total nitrogen, and organic matter increasing with BFB content. The electric conductivity of the 5% BFB soil was 6.89 ds m⁻¹, which is thought to have inhibited pepper growth. Therefore, appropriate biochar treatment (e.g., 2% BFB) has the potential to improve pepper growth and yield, whereas over-treatment (e.g., 5% BFB) has the potential to reduce pepper growth and yield, owing to the effect of biochar on electric conductivity.

Key words: Bead form biochar, Wood waste, Pepper, Soil amendment

INTRODUCTION

Owing to its association with increasing greenhouse gas levels in the atmosphere, global climate change has highlighted the importance of organic carbon storage, particularly in soil (Han *et al.*, 2016). Nutrient management in agricultural land, such as continuous application of organic matter, improved fertilizer utilization efficiency and minimization of soil nutrient loss, is a good way to increase organic carbon content in the soil (Lee, 2013; Lee *et al.*, 2016). Biochar, a solid carbonaceous material that is produced by pyrolyzing biomass under limited oxygen conditions (Oh and Shinogi, 2013; Sohi, 2012), has emerged as a promising carbon isolation measure (Lehmann and Joseph, 2015). During pyrolysis, carbon in the biomass is transformed from easily decomposable carbon to stable carbon, and increasing the pyrolysis temperature reduces biochar recovery rate and increases its carbon ratio. As carbon ratio increases, the specific surface area increases and affects the biochar's adsorption ability. Therefore, the treatment of soil with biochar

suppresses greenhouse gas generation and has carbon storage effect (Lehmann, 2007). When used for soil improvement, biochar can increase the productivity of crops by improving soil acidity, water and nutrient retention, air permeability, and the growth of soil microorganism (Novak *et al.*, 2009; Spokas *et al.*, 2009; Atkinson *et al.*, 2010; Kwapinski *et al.*, 2010; Choi, 2012; Yoo and Kang, 2012; Woo, 2013). A variety of byproducts, including agricultural byproducts, livestock byproducts, marine byproducts, and sewage sludge, can be utilized in the production of biochar, so that the costs of purchasing and securing raw materials are very low (Cao and Harris, 2010; Cantrell *et al.*, 2012). Because it semi-permanently sequesters carbon in the soil, biochar is considered to be an effective soil amendment (Oh *et al.*, 2014; Oh *et al.*, 2017; Woo, 2013). Biochar can be used as a soil conditioner, owing to its high cation exchange capacity, pH, and specific surface area, and because biochar includes stable aromatic ring structures that are not decomposed by soil microorganisms or environmental factors, the use of biochar as a soil amendment can ensure long-term soil management (Choi, 2012).

Pepper is a widely used vegetable in the world and it occupies an important horticultural position in Korea, but it is dependent on imports because of insufficient production. In 2012, the gross area and the production are 946 ha and 3,235 tons, respectively. So, there are various efforts to produce high quality peppers (Park *et al.*, 2016; Shin *et al.*, 2018). Jeong *et al.*, (2006) reported that treating cultivated pepper plants with a mixture of charcoal powder and wood vinegar improved crop growth. Lee and Kim (2001) reported that charcoal had positive effects on the growth of *Thuja occidentalis*. However, the properties of biochar are dependent on both the raw

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material and production process, and it is difficult to define the effects of biochar accurately because it is in the early stages of research (Smith *et al.*, 2010; Oh *et al.*, 2017).

The objective of the present study was to investigate the effect of bead-form biochar (BFB) on the growth of pepper (*Capsicum annuum* L.).

MATERIALS AND METHODS

Study site and soil collection

The present study was conducted in a greenhouse at Chungnam National University in Daejeon, Korea, from April 6 to June 22, 2017, using Korean chili peppers (*C. annuum* 'Buja'; Farmhannong. Co., Ansong, Korea). Soil sample was collected from a research farm belonging to Chungnam National University by taking samples at ~10 cm from the surface and was homogenized by sieving (mesh size, < 2 mm). The soil characterized as alkaline, with relatively low electrical conductivity, available P_2O_5 , and organic matter (Table 1).

Biochar production

The biochar used in the present study was prepared

by pyrolyzing wood waste at 300°C for 3 h under limited oxygen conditions (i.e., in an MF21GS muffle furnace; Jeio Tech, Korea). However, because a pulverized powder formulation was easily dispersed in the soil and could have been by infiltration or runoff, the biochar was mixed with sodium alginate and formed into beads. The BFB was produced by mixing 0.5% sodium alginate solution, 0.5% biochar 40% (v/v), and 1.5% sodium alginate solution, and the mixture was left in 1.0% calcium nitrate solution for at least 20 min (Fig. 1). After drying the formed beads at 60°C, it was prepared by mixing BFB (40%), gypsum (15%), and peat moss (45%; Fig. 2.).

Experimental design

Wagner pots (1/5000 a; 16.5 cm height, 20 cm diameter at top, 13.5 cm diameter at base) were filled with soil containing 0, 2, or 5% BFB by mass and arranged in a randomized complete block design, with three treatments and five replicates per treatment. The pots were randomly rotated each day to different positions within their respective blocks, and the pots were watered once a day. An N- P_2O_5 - K_2O fertilizer (19.0–6.4–10.1) kg/10 a was applied according to the recommendation for crops (NAAS, 2010). At 92 d after sowing, pepper plants were

Table 1. Selected chemical properties of soil used in the present study

Sample	pH (1:5)	EC (ds m ⁻¹)	Av. P_2O_5 (mg kg ⁻¹)	Element content (%)		C/N ratio	OM (%)	Ex. cation (cmol. kg ⁻¹)		
				Carbon	Nitrogen			K ⁺	Ca ²⁺	Mg ²⁺
Soil	8.04±0.09	0.53±0.09	174.8±12.0	0.85±0.01	0.16±0.02	5.05±0.71	1.46±0.03	0.97	12.86	1.27
Pepper Optimum range	6.0 ~ 6.5	2.0 less	450~550	–	–	–	10~15	0.70~0.80	5.0~6.0	1.5~2.0

Abbreviation: EC, electrical conductivity; Av. P_2O_5 , available phosphate; OM, organic matter; Ex. Cations, Exchangeable cations

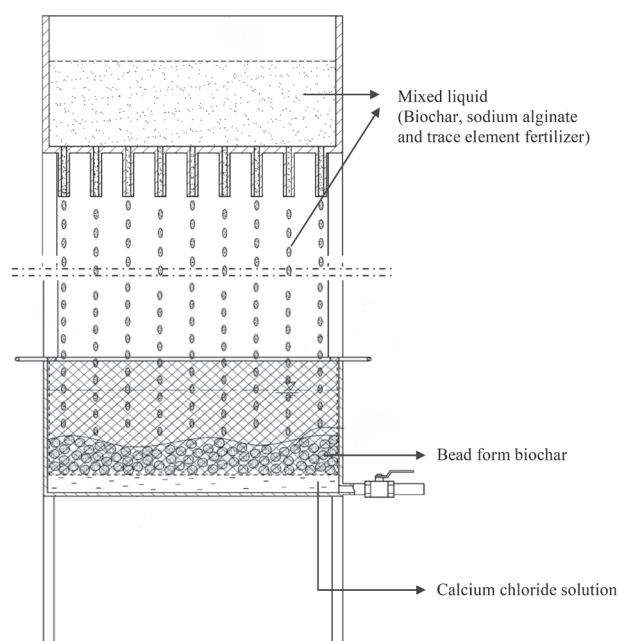


Fig. 1. Bead-form biochar production.



Fig. 2. Bead-form biochar produced during the present study.

transplanted into the pots.

Pepper growth characteristics

At 77 d after transplantation, the growth of the pepper plants was investigated by measuring height, stem diameter, fresh shoot weight, shoot water content, and leaf chlorophyll content, as well as fruit number, total fruit weight, fruit size (length and diameter), and fruit sweetness. Plant height was measured as the distance from the stem to the tip of the longest stem, and stem diameter was measured at the lowest part of the stem. Water content was measured by drying shoots in an oven (80°C) for at least 48 h. Chlorophyll content was measured at the center of leaves using a chlorophyll meter (SPAD-502; Minolta, Japan). Meanwhile, a mean fruit size was determined by the largest five fruits of each plant, and fruit sweetness was measured using a sweetness meter (Hand-held refractometer, Model N-1 α , ATAGO, Tokyo, Japan) and juice extracted from the pepper.

Soil and biochar analysis

The soil and biochar samples were analyzed using the method for Analytical methods of soil, water quality, and liquid fertilizer (NAAS, 2013). The soil samples were air-dried for 14 d and then sifted through a 2-mm sieve, after which the pH and electrical conductivity (EC) were measured using a pH meter and EC meter (ORION Versa Star Pro; Thermo Scientific, Inc., USA) through electrochemical analysis, organic matter (OM) and total nitrogen (T-N) were determined using a CN analyzer (Eager 300; Thermo Scientific, Inc. USA), available phosphate was measured by the Lancaster method using a UV-VIS spectrophotometer (Evolution 300; Thermo Scientific, Inc. USA), and exchangeable cations (K⁺, Ca²⁺, and Mg²⁺) were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES; GBC Scientific, Australia) after leaching with 1N NH₄OA_c solution (pH 7.0).

RESULTS AND DISCUSSIONS

Biochar characteristics

The chemical properties of the wood-derived biochar used for the present study are shown in Table 2. The pH and EC of coffee sludge biochar are 6.16 and 98.98 dS m⁻¹, respectively. According to previous studies, BFB is shown to alkaline pH by alkali salts separated from the biomass organic material during pyrolysis (Ahmad *et al.*, 2012). However, the pH of the BFB used in the present study was slightly acidic, likely owing to the addition of sodium alginate and calcium chloride during BFB production. Furthermore, the high EC is likely caused by the concentration of various salts within the ash, owing to the loss of volatile substances during pyrolysis (Cantrell *et al.*, 2012) and to the use of calcium chloride in BRB production. The biochar was also characterized by 26.66% organic matter, 2.74% total nitrogen, 1016.2 mg kg⁻¹ available phosphate, and the presence of exchangeable K⁺, Ca²⁺, and Mg²⁺.

Effects of biochar on pepper growth

The effects of BFB application on pepper growth are shown in Table 3 and Fig. 3. Plant height was increased by 16.7% under the 2% BFB treatment (93.3 \pm 10.2 cm), when compared to the control (79.9 \pm 8.0 cm), but reduced by 25.0% (59.6 \pm 25.3 cm) under the 5% BFB treatment. Meanwhile, plant weight was increased by 48.2% under the 2% BFB treatment (63.0 \pm 6.8 g), when compared to the control (42.5 \pm 4.1 g), but decreased by 23.2% under the 5% BFB treatment (32.6 \pm 12.4 g). Therefore, plant growth was promoted by the application of 2% BFB but inhibited by the application of 5% BFB.

Similarly, fruit number and total fruit weight were increased by 33.3 and 39.0% under the 2% BFB treatment (12.0 \pm 0.9 per plant, 56.5 \pm 8.6 g), when compared to the control (9.0 \pm 0.8 per plant, 40.5 \pm 11.7 g) whereas the parameters were reduced by 38.8 and 61.7% under

Table 2. Selected chemical properties of the biochar used in the present study

Sample	pH (1:5)	EC (ds m ⁻¹)	Av. P ₂ O ₅ (mg kg ⁻¹)	Element content (%)		C/N ratio	OM (%)	Ex. cation (cmolc kg ⁻¹)		
				Carbon	Nitrogen			K ⁺	Ca ²⁺	Mg ²⁺
Biochar	6.16 \pm 0.02	98.98 \pm 2.92	1016.2 \pm 23.5	15.46 \pm 2.37	2.74 \pm 0.23	5.65 \pm 0.84	26.66 \pm 4.09	4.92 \pm 0.28	104.9 \pm 0.5	2.61 \pm 0.28

Abbreviation: EC, electrical conductivity; Av. P₂O₅, available phosphate; OM, organic matter; Ex. Cations, Exchangeable cations

Table 3. Growth characteristics of pepper plants under different biochar treatments

Treatment	plant			Fruit							Chlorophyll
	Height	Stem diameter	Weight	Water content	Number	Total weight	Weight per fruit	Length	Diameter	Sweetness	
	(cm)	(cm)	(g)	(%)	(per plant)	(g)	(g/ea)	(cm)	(cm)	(Brix)	(SPAD)
Control	79.7 \pm 8.0	0.9 \pm 0.08	42.5 \pm 4.1	72.8 \pm 0.6	9.0 \pm 0.8	40.5 \pm 11.7	4.4 \pm 1.1	9.1 \pm 1.0	1.30 \pm 0.06	7.2 \pm 1.6	41.3 \pm 1.1
Biochar 2%	93.3 \pm 10.2	0.9 \pm 0.03	63.0 \pm 6.8	74.4 \pm 0.8	12.0 \pm 0.9	56.5 \pm 8.6	4.4 \pm 0.5	10.5 \pm 1.1	1.34 \pm 0.09	7.7 \pm 1.4	57.1 \pm 3.3
Biochar 5%	59.6 \pm 25.3	0.8 \pm 0.18	32.6 \pm 12.4	79.9 \pm 0.9	5.5 \pm 0.5	15.5 \pm 6.8	2.9 \pm 1.4	7.8 \pm 1.7	0.96 \pm 0.20	4.9 \pm 1.2	53.7 \pm 7.2

the 5% BFB treatment (5.5 ± 0.5 per plant, 15.5 ± 6.8 g). Fruit weight, length, diameter, and sweetness were also greater under the 2% BFB treatment than under the control (0% BFB) treatment and were lower under the 5% BFB treatment.

However, chlorophyll content was reduced by 38.2% under the 2% BFB treatment (57.1 ± 3.3 SPAD), when compared to the control (41.3 ± 1.1 SPAD). Therefore, appropriate biochar treatment (e.g., 2% BFB) has the potential to improve pepper growth and yield, whereas over-treatment (e.g., 5% BFB) has the potential to reduce pepper growth and yield.

Effects of biochar on soil chemistry

The effects of BFB on soil chemistry are shown in Table 4. The pH values of the soils under the 2 and 5% BFB treatments were 7.12 and 6.94, respectively, and the addition of BFB was observed to slightly reduce the soil pH. Previous studies have reported that coffee sludge biochar can both improve soil acidity and reduce levels of heavy metals, thereby regulating their uptake by plants (Lim *et al.*, 2015; Koh *et al.*, 2016). The acidic pH of BFB can likely be attributed to the sodium alginate and calcium chloride added during bead production.

In general, BFB also increased the EC of the soil. For example, the EC of the soil under the 5% BFB treatment was more than 3.5 times greater than the pepper cultivation optimum range. It is likely that the EC of BFB was increased by the addition of sodium alginate and calcium chloride during BFB production and that the growth-inhibiting effects of the 5% BFB treatment can be attributed to the elevating effects of BFB on soil EC, which subsequently inhibits crop growth.

BFB treatment also increased the organic matter, nitrogen, and exchangeable K and Ca contents of the soil but reduced the exchangeable magnesium content. Therefore, appropriate biochar treatment (e.g., 2% BFB)

has the potential to improve pepper growth and yield, whereas over-treatment (e.g., 5% BFB) has the potential to reduce pepper growth and yield, owing to the effect of biochar on EC.

CONCLUSIONS

The present study was conducted in a greenhouse at Chungnam National University, Daejeon, Korea, from April 6 to June 22, 2017, in order to elucidate the properties of wood-derived BFB, as well as its effectiveness as a soil amendment.

1. Plant height was increased by 16.7% under the 2% BFB treatment (93.3 ± 10.2 cm), when compared to the control (79.9 ± 8.0 cm), but reduced by 25.0% (59.6 ± 25.3 cm) under the 5% BFB treatment.
2. Similarly, fruit number and total fruit weight were increased by 33.3 and 39.0% under the 2% BFB treatment (12.0 ± 0.9 per plant, 56.5 ± 8.6 g), when compared to the control (9.0 ± 0.8 per plant, 40.5 ± 11.7 g), whereas the parameters were reduced by 38.8 and 61.7% under the 5% BFB treatment (5.5 ± 0.5 per plant, 15.5 ± 6.8 g).
3. The addition of BFB was observed to slightly reduce the soil pH. The acidic pH of BFB can likely be attributed to the sodium alginate and calcium chloride added during bead production.
4. In general, BFB increased the EC of the soil. For example, the EC of the soil under the 5% BFB treatment was more than 3.5 times greater than the pepper cultivation optimum range. It is likely that the growth-inhibiting effects of the 5% BFB treatment can be attributed to the elevating effects of BFB on soil EC, which subsequently inhibits crop growth.
5. Therefore, appropriate biochar treatment (e.g., 2% BFB) has the potential to improve pepper growth and yield, whereas over-treatment (e.g., 5% BFB) has the

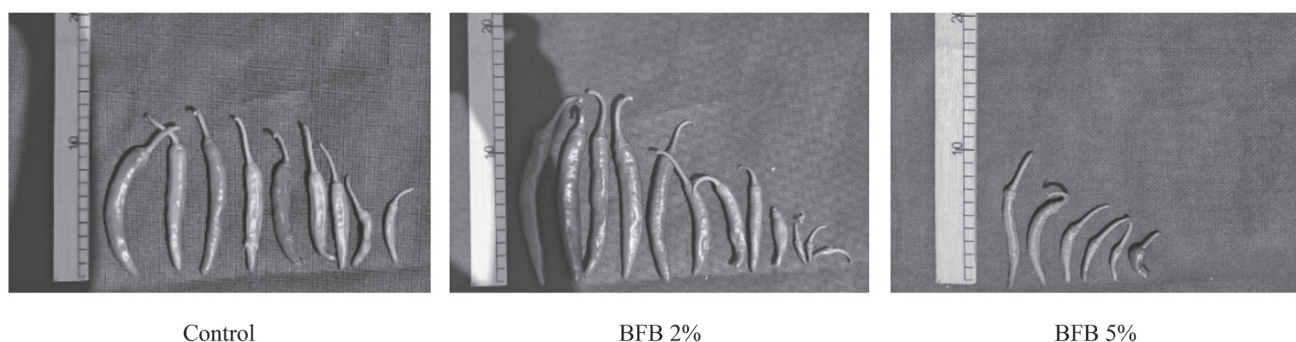


Fig. 3. Pepper plants grown under different biochar treatments.

Table 4. Effects of biochar treatment on selected soil characteristics after pepper harvest

Treatment	pH (1:5)	EC (ds m ⁻¹)	Avail. P ₂ O ₅ (mg kg ⁻¹)	Element content (%)		C/N ratio	OM (%)	Ex. cation (cmol _c kg ⁻¹)		
				C	N			K ⁺	Ca ²⁺	Mg ²⁺
Control	7.29±0.02	0.38±0.03	174.2±2.6	0.63±0.08	0.05±0.01	11.29±2.37	1.09±0.13	0.12±0.02	8.57±0.66	0.74±0.00
Biochar 2%	7.12±0.05	2.70±1.57	225.6±4.3	0.84±0.21	0.08±0.01	10.38±1.54	1.44±0.36	0.16±0.03	10.15±1.18	0.47±0.07
Biochar 5%	6.94±0.05	6.89±2.22	242.0±3.1	1.08±0.34	0.10±0.02	10.61±1.39	1.86±0.58	0.22±0.02	13.28±1.24	0.47±0.03

potential to reduce pepper growth and yield, owing to the effect of biochar on EC.

AUTHOR CONTRIBUTIONS

Jae-Han LEE, Su-Hun KIM, Ji-Seon LIM, Jeon-Huk Yoo, Jae-Hong KIM and Jung-Hyun PARK carried out analysis and interpretation of data. Ho-Cheol LEE and Yeon-Kyu LEE produced bead-form biochar. Yoshiyuki SHINOGI verified the data. Taek-Keun OH and Jwakyung Sung supervised the project and wrote the paper. All authors commented on the manuscript.

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REFERENCES

- Ahmad, M., S. S. Lee, X. Dou, D. Mohan, J. K. Sung and J. E. Yang 2012 Effects of pyrolysis temperature on soybean stover- and peanut shell-derived biochar properties and TCE adsorption in water. *Bioresource Technology*, **118**: 536–544
- Atkinson, C. J., J. D. Fitzgerald and N. A. Hipps 2010 Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and Soil*, **337**: 1–18
- Cantrell, K. B., P. G. Hunt, M. Uchimiya, J. M. Novak and K. S. Ro 2012 Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. *Bioresource Technology*, **107**: 419–428
- Cao, X. and W. Harris 2010 Properties of dairy-manure-derived biochar pertinent to its potential use in remediation. *Bioresource Technology*, **101**: 5222–5228
- Choi, Y. R. 2012 *The Characteristics of the Biochar Produced from Waste Biomass for Improvement of Acidic Soils*. Master Thesis, Kwangwoon University. Seoul, Korea [in Korean]
- Han, K. H., Y. S. Zhang, K. H. Jung, H. R. Cho, M. J. Seo and Y. K. Son 2016 Statistically estimated storage potential of organic carbon by its association with clay content for Korean upland subsoil. *Korean Journal of Agricultural Science*, **43**: 353–359 [In Korean]
- Jeong, C. S., I. J. Yun, J. N. Park, J. H. Kyoung, J. P. Kang, S. J. Lee, T. S. Jo, and B. J. Ahn 2006 Effect of wood vinegar and charcoal on growth and quality of sweet pepper. *Korean Journal of Horticultural Science and Technology*, **2**: 177–180
- Koh, I. H., J. G. Kim, G. S. Kim, M. S. Park, D. M. Kang and W. H. Ji 2016 Stabilization of Agricultural Soil Contaminated by Arsenic and Heavy Metals using Biochar Derived from Buffalo Weed. *J. Soil Groudw. Environ.*, **21**(6): 87–100 [in Korean]
- Kwapinski, W., C. M. P. Byrne, E. Kryachko, P. Wolfram, C. Adley, J. J. Leahy, E. H. Novotny and M. H. B. Hayes 2010 Biochar from Biomass and Waste. *Waste and Biomass Valorization*, **1**(2): 177–189
- Lee, D. W. and B. R. Kim 2001 Effect of carbonized wastewoods on soil improvement. *Journal of Korea Forestry Energy*, **20**: 1–5 [in Korean]
- Lee, H. S. 2013. *Effects of biochar on enzyme activities and greenhouse gas in agricultural soils*. Master's Degree thesis, Yonsei Univ., Seoul [in Korean]
- Lee, S. B., J. E. Lim, Y. J. Lee, J. K. Sung, D. B. Lee and S. Y. Hong 2016 Analysis of components and applications of major crop models for nutrient management in agricultural land. *Korean Journal of Agricultural Science*, **43**: 537–546 [in Korean]
- Lehmann, J. and S. Joseph 2015. *Biochar for environmental management: An introduction, in biochar for environmental management: Science, Technology and Implementation*. Earthscan, London. pp. 1–11
- Lehmann, J. 2007. A handful of carbon. *Nature*, **447**: 143–144
- Lim, J. E., S. S. Lee and Y. S. Ok 2015 Efficiency of Poultry Manure Biochar for Stabilization of Metals in Contaminated Soil. *Journal of Applied Biological Chemistry*, **58**(1): 39–50 [in Korean]
- NAAS. 2013. *Analytical methods of soil, water quality and liquid fertilizer*. RDA. Juenju, Korea [in Korean]
- NAAS. 2012. *Research and Analysis Criteria for crops*. RDA. Juenju, Korea [in Korean]
- Novak, J. M., W. J. Busscher, D. A. Laird, M. Ahmedna, D. W. Watts and M. A. S. Niandou 2009 Impact of Biochar Amendment on Fertility of a Southeastern Coastal Plain Soil. *Soil Science*, **174**(2): 105–112
- Oh, T. K., J. H. Lee, S. H. Kim and H. C. Lee 2017 Effect of biochar application on growth of Chinese cabbage (*Brassica chinensis*). *Korean Journal of Agricultural Science*, **44**: 359–365 [in Korean]
- Oh, T. K. and Y. Shinogi 2013 Characterization of the pyrolytic solid derived from used disposable diapers. *Environmental Technology*, **34**(24): 3153–3160
- Oh, T. K., Y. Shinogi, S. J. Lee and B. S. Choi 2014 Utilization of biochar impregnated with anaerobically digested slurry as slow-release fertilizer. *J. Plant Nutr. Soil Sci.*, **177**: 97–103
- Park, B. S., C. S. Han, T. H. Kang and H. S. Lee 2016 Economic effect analysis of flame retardant aluminum screen development. *Korean Journal of Agricultural Science*, **43**: 496–505
- Shim, S. W., H. J. Kim, J. Y. Park, T. M. Bae, J. H. Min, J. S. Lee, S. J. Kim and Y. S. Hwang 2018 Effect of natural anti-microbe chemicals, chitosan and stevia, on the growth, yield, and quality of chili peppers. *Korean Journal of Agricultural Science*, **45**: 19–27
- Smith, J. L., H. P. Collins, V. L. Bailey 2010 The effect of young biochar on soil respiration. *Soil Biology and Biochemistry*, **42**: 2345–2347
- Sohi, S. P., 2012. Carbon storage with benefits. *Science*, **338**(6110): 1034–1035
- Spokas, K. A. and D. C. Reicosky 2009 Impacts of Sixteen Different Biochars on Soil Greenhouse Gas Production. *Annals of Environmental Science*, **3**: 179–193
- Woo, S. H. 2013 *Biochar for Soil Carbon Sequestration*. Clean Tech., **19**(3): 201:211 [in Korean]
- Yoo, G. Y. and H. J. Kang 2012 Effects of Biochar Addition on Greenhouse Gas Emissions and Microbial Responses in a Short-Term Laboratory Experiment. *Journal of Environmental Quality*, **41**(4): 1193–1202

