

Estimation of soil carbon sequestration and profit analysis on mitigation of CO₂-eq. emission in cropland cooperated with compost and biochar

JoungDu Shin¹ · Seung Gil Hong¹ · SunIl Lee¹ · SungChang Hong¹ · JongSik Lee¹

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Abstract Only a few have evaluated the mitigation of greenhouse emissions and profit analysis along with soil carbon sequestration for corn cultivation. This experiment was conducted to evaluate the carbon sequestration and mitigation of greenhouse gas emissions as well as their profit analysis with different composts mixed with biochar during corn cultivation. This experimental data provided the second year of corn cultivation. The soil type used was clay loam. The application amounts of synthetic fertilizer and biochar were 220–30–155 kg ha⁻¹ (N–P–K) as the recommended amount after soil analysis and 2600 kg ha⁻¹ based on 1.3% of soil bulk density. For the biannual experimental results, it appeared that carbon sequestration in cow manure cooperated with biochar was highest at 2.3 tons ha⁻¹ and recovered from 67.3 to 78.5% with biochar application. Furthermore, mitigation of CO₂-eq. emission as greenhouse gases was estimated to be at 7.3–8.4 MT ha⁻¹, and its profit was evaluated from \$7.2 to 8.4 as lowest, from \$57.2 to 66.6 as medium and from \$139.7 to 162.7 as highest per hectare regardless of organic compost types used. For agricultural practice in Korea, it is evaluated that the market price of CO₂ in corn field cooperated with 2600 kg ha⁻¹ of biochar application ranged from \$57.2 to 162.7 per hectare in Korean Climate Exchange. For corn biomass, the treatment with biochar application did not significantly decrease compared with the only organic compost application. Based on these experimental results, it might be applied for carbon trading

with clean development mechanism for agricultural practices.

Keywords Biochar · Composted manure · Corn cultivation · Soil carbon sequestration

Introduction

Land use and land use change in greenhouse gas emissions for agriculture sector, particularly CO₂, are estimated to contribute at 20% of the total amount of greenhouse gases. It described about direct and indirect effects of climate change on crop productivity [1–3]. It indicates that 70–90% of CO₂ emitted to the atmosphere has been attributed to overconsumption of fossil fuel [4, 5]. The important contributors in enhancing CO₂ content in the atmosphere are considered to be burning the plant residues, tillage, application of synthetic fertilizers and land use change [6].

Biomass is composed of carbon materials including plant residues, animal wastes, excrements and biowastes from households and industries [7]. Biomass produced from agricultural land is potential energy resource as well as source of greenhouse gases emissions, causing significant environmental problems such as point and nonpoint pollution sources. Estimation of energy potential production from plant residues and animal wastes is globally about 34 EJ (exajoule = 10¹⁸ joules) out of a total 70 EJ [8]. It is estimated that over 50 million tons out of 80 million tons of organic wastes is produced every year for agricultural sector in Korea [9]. Therefore, the interest on country with insufficient biomass resources as a Korea is skyrocketing.

✉ JoungDu Shin
jdshin1@korea.kr

¹ Department of Agricultural Environment, National Institute of Agricultural Sciences, Rural Development Administration, Wanju 55365, Republic of Korea

Biochar is the carbon-rich byproduct produced by thermal treatment for biomass conversion under no oxygen with either pyrolysis or liquefaction technologies. Biochar from biomass conversion technology has recently gained attention to improve the soil fertility and to store soil carbon when cooperated with soil. Its positive effects on the agro-ecosystem have been considered to indirectly derive, to adsorb and to hold the plant nutrients [10, 11].

For important roles of soil carbon cycle over the world, it was evaluated to approximately be 55–878 billion tons (GT) of carbon to the total atmospheric CO₂ [12]. The total soil carbon is evaluated to be over 2250 GT on surface of 1 m depth in the earth [13].

Input and output of soil carbon are affected by management by two biotic processes: production of organic matter in the soil and decomposition of organic matter by soil microbes. For the effect of biochar produced from rice husks during crop cultivation, it was estimated that plots treated with aerobic swine digestate, cow and pig composts might store the soil carbon by 38.9, 82.2 and 19.7% in soil, respectively [14]. The market prices of CO₂ offsets in the European Climate Exchange varied between \$4.1 and \$7.9 per MT CO₂ in 2016 [15]. During the same year, those of CO₂ in Korean Climate Exchange (KCX) were ranged from \$7.9 to \$19.3 per 1 Korean Allowance Unit (KAU) [16].

Therefore, this experiment was conducted to evaluate the mitigation of greenhouse gas emissions as well as their profit analysis along with soil carbon sequestration, particularly in clay loam soil during corn cultivation.

Materials and methods

For the biannual experiment, the corn variety used was Miback 2 which was planted with 30 × 60 cm of planting distance in clay loam soil. Corn cultivation was performed with crop cultivation's guidelines from Rural Development Administration. For the experiment, the treatments consisted of cow compost (CC) and pig compost (PC), swine aerobic digestate (AD) and their biochar combination. Synthetic fertilizers were applied with 220–30–155 kg ha⁻¹ (N–P–K) in whole basal application of phosphorous (P₂O₅) and potassium (K₂O). It was specifically applied half on basal application at 3 days before transplanting and half for additional application for urea, based on chemical components of soil analysis before experiment. Application amounts of PC and CC were applied with 25,000 and 5500 kg ha⁻¹ into soil, respectively, as the recommended application rates based on soil test of chemical components before the experiment. AD was applied with 100 ton ha⁻¹ that was equivalent of 16% of water-holding capacity. Biochar produced from rice husk is purchased from local

company. Chemical properties of soil used are presented in Table 1.

Application amount of biochar into soil was 2600 kg ha⁻¹ based on 1.3% of soil bulk density. Biochar produced from rice husks was also used. Physiochemical properties of biochar used are presented in Table 2.

Soil samples were collected for every 15-day intervals after corn transplanting during cultivation period. The soil was dried and passed through 2-mm sieve. And then these samples stored in storage until analyzing the chemical properties.

Soil chemical components as total nitrogen and total carbon (TC) were analyzed by total organic carbon analyzer (Elementar Vario EL II, Hanau, Germany). The combustion temperature was 950 °C, and tungsten trioxide (WO₃) was used as the catalyst. The carbon sequestration by biochar application in the cropland is calculated from the differences of residual amount of soil carbon between compost treatment and its application mixed with biochar after corn harvest. Amount of soil carbon sequestration was calculated by the following equation;

$$SS_{TC} = (T_{TC}i - NT_{TC}i) \times SW, \quad (1)$$

where SS_{TC} is sequestration amount of soil carbon, T is treatment of composts with biochar, NT is only treatment with composts, i is date of last sampling which is analyzed the soil carbon content, and SW is soil weight.

Mitigation of CO₂-eq. emission was also estimated by following equation;

$$CO_2\text{-eq.} = SS_{TC} \times CF_{SC}, \quad (2)$$

where SS_{TC} is amount of soil carbon sequestration and CF_{SC} is conversion factor of CO₂ emission from carbon (1 kg C = 3.664 kg CO₂-eq.).

Profit analysis for mitigation of CO₂-eq. emission was also calculated by using the following equation:

$$P = AM \times MP, \quad (3)$$

where P is profit of carbon dioxide trading (\$ ha⁻¹), AM is amount of mitigation of CO₂-eq. emission (MT ha⁻¹), and MP is market prices of CO₂ offsets (\$ per MT CO₂).

Results

Calculation of soil carbon sequestration with biochar application

For total carbon content for raw materials, its biochar was higher at 2.1 times than cow compost. Lowest total carbon content was observed to be cow compost. Biochar is mostly organic carbon as well as the cow compost and pig compost as seen in carbon fractions (Table 3).

Table 1 Physiochemical properties of soil used in this study

Soil Texture	pH (1:5)	EC (dS m ⁻¹)	T-N			Av. P ₂ O ₅	Ex. cations (cmol ⁺ kg ⁻¹)		
			(g kg ⁻¹)				K	Ca	Mg
Clay loam	6.2	2.1	8.7	9.84	603	0.41	6.3	2.5	

Table 2 Characteristics of biochar and pig compost used in this study^a

	pH (1:20)	EC (dS m ⁻¹)	TC ^a %	TOC ^a	TIC ^a	TN ^a
Biochar	9.78	16.53	56.63	53.30	4.25	0.20

^a TC total carbon, TOC total organic carbon, TIC total inorganic carbon and TN total nitrogen

Table 3 Soil carbon fractions and total nitrogen contents of input materials

Input materials ^a	TC g kg ⁻¹	TOC	TIC	TN
CC	271 ± 2	266 ± 2	3.3	15
PC	415 ± 3	348 ± 3	67.0	11
Rice hull	367 ± 4	–	–	3.7 ± 0.3
Biochar-based rice hull	564 ± 1	552 ± 4	11.5	–

^a CC cow compost, PC pig compost

For nitrogen contents of raw materials, the pig compost was higher at 1.5%, while cow compost was lowest at 1.1% (Table 3). Also, the total carbon concentrations of biochar were increased at 19.7% and 1.5 times relatively to the rice husk as initial raw material.

Effects of total soil carbon concentrations with different compost application and their mixtures with biochar during corn cultivation are described in Fig. 1. The effects of biochar for total carbon in soil were defined as total carbon concentrations in the plot with treatment deducted from the total carbon contents in the plot without treatment at the final day of soil sampling after corn harvesting.

It was observed that total carbon was slightly increased with days after transplanting, and its peak was at 15 days after transplanting (Fig. 1). Total carbon concentrations in the treatments mixed with biochar were ranged from 0.96 to 1.24%, and cow compost-treated plot was higher at 1.24% at harvesting stages.

Soil carbon sequestration for biochar application during cultivation period was calculated using Eq. 1 based on cultivation area and soil bulk density (Table 4). With compost applications, residual amounts of soil total carbon were ranged from 10,491 to 13,754 kg ha⁻¹, and its

amount in the cow compost's plot was higher at 13,754 kg ha⁻¹. With cooperation of biochar, the carbon sequestrations ranged from 1976 to 2301 kg ha⁻¹, and the carbon sequestration was appeared to be highest at 78.5% in cow compost's plot (Table 4).

Profit analysis of CO₂ mitigation with biochar application

For carbon sequestration for corn fields cooperated with biochar, mitigation of CO₂-eq. emission was calculated by using Eq. 2 (Table 5). Mitigation of CO₂-eq. emission by biochar application ranged from 7.24 to 8.43 MT ha⁻¹ and was higher at 8.43 MT ha⁻¹ in the cow compost treatment. For profit analysis for mitigation of CO₂-eq. emission (Eq. 3), it appeared that profitability of 2600 kg ha⁻¹ of biochar application for corn cultivation approximately ranged from \$29.7 to 34.6 as lowest, from \$57.2 to 66.6 as medium and from \$139.7 to 162.7 as highest per hectare regardless of organic compost types. Also, it is derived that market price of CO₂ trading during corn cultivation which cooperated with 2600 kg ha⁻¹ of biochar application ranged from \$57.4 to 261.3 per hectare in KCX (Table 5).

Plant growth responses to biochar application

Effects on growth responses as plant height and total biomass in the different compost application and their cooperation with biochar are presented in Table 6. It is shown that plant height and total biomass of corn did not significantly different between compost treatment and its cooperation with biochar.

Discussions

Biochar is mostly organic carbon as well as the cow compost and pig compost as seen in carbon types (Table 3). Biochar might consist of almost non-degradable organic carbon composited of double bonds as contrary to cow and pig composts because it is not occurred soil microbial decomposition for a century as compared with agricultural wastes [17]. Therefore, biochar carbon bonds did not break down and remained in soil for centuries [18]. The effects of biochar for total carbon in soil were defined as the total carbon concentrations in the treatment plots

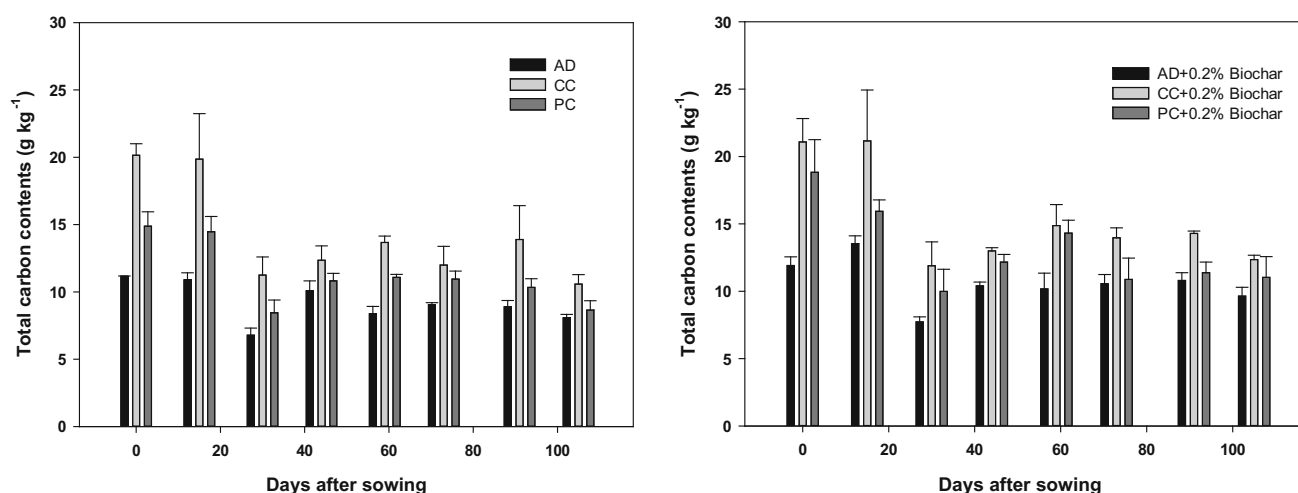


Fig. 1 Changes of total carbon contents in the soil applied with different organic composts and their cooperation with biochar during corn cultivation period (*AD* aerobic digestate, *CC* cow compost, *PC* pig compost)

Table 4 Estimation of carbon sequestration in the soil applied with different composts and their cooperation with biochar during corn cultivation period

Treatments ^a	Compost only	With biochar	C-sequestration	Recovery rates (D) ^b
	(A)	(B)	(B–A)	
	kg ha ⁻¹			(%)
AD	10,491	12,532	2041	70.0
CC	13,754	16,055	2301	78.5
PC	11,245	13,221	1976	67.4

Biochar input; 2600 kg ha⁻¹ (TC; 56.4%)

^a *AD* aerobic digestate, *CC* cow compost, *PC* pig compost

^b D = C/Accumulated application amount of area × (TC/100)

Table 5 Mitigation of CO₂-eq. emission and profit analysis in the soil applied with different composts cooperated with biochar during corn cultivation period

Treatments*	Mitigation of CO ₂ -eq. emission (MT ha ⁻¹)**	Profit (\$ ha ⁻¹)		
		\$4.1 per MT CO ₂	\$7.9 per MT CO ₂	\$19.3 per MT CO ₂
AD	7.48	30.66	59.08	144.33
CC	8.43	34.57	66.60	162.72
PC	7.24	29.68	57.20	139.73

* *AD* aerobic digestate, *CC* cow compost, *PC* pig compost

** 1 kg C = 3.664 kg CO₂-eq

deducted total carbon concentrations in the non-application plot at the final day of soil sampling after corn harvesting. It appeared that recovery rate of total carbon for biochar application was different with only compost treatments because of having a different total carbon's content in the different composts.

For carbon sequestration, the effects of accumulated biochar might be attributed to increase the differences of total carbon's concentrations between the compost treatment and its treatment cooperated with biochar after corn harvesting. On the other hand, it indicated that total carbon's contents were increased with days after transplanting through corn cultivation periods [14]. This difference could

be due to the effect of plant growth responses whether it is good or bad based on their soil carbon utilization ability (Fig. 1 and Table 6). Lehmann indicated that biochar can storage soil carbon up to 50% of the initial carbon of raw material [17]. However, it was observed that applications of *AD*, *CC* and *PC* can sequester carbon by 70.0, 78.5 and 67.4% in the soil, respectively, when mixed with biochar from rice husks. The reason of high soil carbon sequestration in the treatment of pig compost mixed with biochar could be attributed to originally have the high content of total carbon in *CC* because the cow had physical digestion (Table 3), but *PC* is also easy to decompose total carbon into plant nutrient because pig had chemical digestion to

Table 6 Plant responses to applications of different organic composts and their cooperation with biochar

Treatments ^a		Plant height (cm)	Fresh biomass weight (kg ha ⁻¹)
Compost only	CC	192.0 ± 4.8	62,863 ± 5613
	PC	202.3 ± 3.3	67,244 ± 2524
	AD	193.5 ± 2.3	64,326 ± 2451
With biochar	CC	188.2 ± 7.6	60,509 ± 4897
	PC	192.3 ± 3.3	62,346 ± 6070
	AD	185.5 ± 7.9	61,217 ± 5194

^a AD aerobic digestate, CC cow compost, PC pig compost

livestock's feed. For the sandy loam soil, it has been reported that mitigation of CO₂-eq. emission in AD, CC and PC mixed with 1300 kg ha⁻¹ of biochar application was 0.16 MT CO₂ ha⁻¹, 0.87 MT CO₂ ha⁻¹ and 14.58 MT CO₂ ha⁻¹, respectively [19].

The low, medium and high values were derived from combination of KAU and EUA. The differences in carbon trading price across markets are in part due to the currently optional fact of participation in the CCX and that no entity is legally required to participate in this exchange. However, discussions on recent policy at the national level suggest an enhanced momentum toward a binding national carbon market in Korea. It was previously traded about \$7.9 per 1 KAU on January 12, 2015, because of market price of CO₂ trading in KCX. Therefore, it is calculated that profitability ranged from \$0.16 to \$4.96 for AD, from \$0.87 to \$26.97 for CC and from \$14.58 to \$451.98 for PC mixed with 1300 kg of biochar application per hectare during corn cultivation in the cropland [19]. It is considered that these differences might be due to the different compost and soil types.

For soil carbon sequestration, application of biochar in the corn field was significantly not only caused damage of corn growth, but also not decreased the total biomass of corn. Also, it appeared that plant height and total biomass were not significantly different between compost treatments and their cooperation with biochar [14]. Collins has found a decline in the root–shoot ratio of wheat in Quincy sand soil amended with biochar from peanut hull [20]. Also, it was indicated that inhibition of crop growth in some experiments with biochar has been attributed a decrease the available ammonium in soil [21]. However, application of composts mixed with biochar could be a potential way to sequester soil carbon for agricultural practices. For further study, application of biochar pellet mixed with PC in cropland needs to be expounded particularly for soil carbon sequestration in practice to save labor as well as to reduce nonpoint sources.

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