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Profit Analysis by Soil Carbon Sequestration with Different Composts and Cooperated with Biochar during Corn (*Zea mays*) Cultivation Periods in Sandy Loam Soil

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Abstract

Despite the ability of biochar to enhance soil fertility and to sequester soil carbon, its potential reduction of green house gas emissions and profit analysis with different organic composts and cooperated with biochar for crop cultivation have been a few evaluated. This study was conducted to estimate their greenhouse gas emission reduction and profit analysis by soil carbon sequestration with different organic composts and cooperated with biochar application during corn cultivation periods. For the experiment, the treatments were consisted of aerobic digestate of swine wastes (AD), pig compost as the control (PC), cow compost (CC) and pig compost cooperated with 1% biochar (PC + 1% biochar). The soil texture used in this study was sandy loam, and application rates of chemical fertilizer were 190-39-221 kg·ha^{-1} (N-P_2O_5-K_2O) as recommended amount after soil test. The soil samples were periodically taken at every 15 day intervals during the experimental periods. It was observed that soil carbon sequestration by AD, CC and PC + 1% biochar application was estimated to be 429 kg·ha^{-1}, 2366 kg·ha$^{-1,}$ and 3978 kg·ha^{-1}, and their CO_2-*e* emission reductions were estimated to be 0.16 tones for AD, 0.87 tones for CC, and 14.58 tones for PC + 1% biochar per hectar for corn cultivation periods. Their profits were estimated at $14.58 for lowest and $451.90 for highest. In Korea Climate Exchange, it was estimated to be $115.20 per hectar of corn cultivation with PC + 1% biochar. So, the price of CO_2 per hectar for corn cultivation with PC + 1% biochar was high at 16.8 times relative to cow compost treatment only. For the plant growth response, it was observed that plant height and fresh ear yield were not significantly different among the treatments. Therefore, these experimental results might be fundamental data for assuming a carbon trading mechanism exists for biochar soil application in agricultural practices.

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Keywords

Biochar, Greenhouse Gas Emission Mitigation, Soil Carbon Sequestration, Compost

1. Introduction

Global warming is becoming a critical issue around the world. Numerous researchers and organizations have been involved in reducing the greenhouse gases from various sources [1]-[3]. Since many countries recognized the importance of greenhouse gases (GHG), including methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O), the estimation of GHG emission was conducted for a comprehensive understanding of the effect of GHG in each country in terms of global warming and the significant mitigation potential [2] [4]-[6]. Biomass is composed of carbon rich materials including all plants, animals, nutrients, excrements and bio-waste from households and industries [7]. Unused or discarded biomass residues from agricultural areas are potential energy resource, but at same time can be a source of GHG emissions, causing a significant environmental problem. Potential energy production from crop and animal residues is globally estimated to be about 34 EJ (exajoule = 10^{18} joules) out of a total 70 EJ [8]. In Korea, it is estimated that over 50 million tones of organic wastes are produced every year in agricultural sector out of over 80 million tones [9]. The interest of biomass in resource-poor country such as Korea is therefore increasing.

Biochar is the carbonaceous product obtained by heat treatment of biomass under limited or no oxygen (pyrolysis or liquefaction technology). Biochar has recently gained attention for its potential, when cooperated with soil to improve soil fertility and to store carbon removed from the atmosphere by plants. Biochar's positive effects on the soil ecosystem, including both plants and microbes, have been proposed to derive either directly from nutrients within biochar itself or indirectly its ability to absorb and retain nutrients [10]-[12].

Soil plays significant roles in global carbon cycle. It is estimated that soils have contributed as much as 55 to 878 billion tones (GT) of carbon to the total atmospheric CO_2 [13]. The total soil carbon consists of the soil organic and inorganic carbons, estimated to be approximately over 2250 GT in the top 1 meter depth [14]. While the soil organic carbon contributes approximately 25% of overall soil carbon inventory, agricultural practices have more propound influence on the change of soil organic carbon both in the short and the long term. Thus carbon sequestration in soils, *i.e.*, increasing soil organic carbon through proper management of biochar input, provides a multitude of environmental benefits. For estimating the value of potential CO_2 offset, a low and high value of $1 and $31 MT CO_2 is used [15] [16], assuming a carbon trading mechanism exists for biochar application in the agricultural practices.

Regarding the effect of biochar application, when biochar from rice hulls is cooperated with soil (0.2% of soil weight), applications of aerobic swine digestate, cow compost, and pig compost can sequester C by 38.9%, 82.2% and 19.7% in soil, respectively [17]. For the profit analysis, it is reported that the market price of CO_2 in corn cultivation with 0.2%, 1% and 2% biochar application is $35.6, $115.3 and $428.2 per hectar in Korea Climate Exchange (KCX), respectively [18].

Therefore, this study was conducted to estimate their carbon sequestration, potential reduction of greenhouse gas emission and profit analysis with different organic composts and cooperated with biochar application during corn cultivation periods.

2. Materials and Methods

The corn variety used in this experiment was Miback 2 Ho those kernel is white and sticky, and planting distance was 30 × 60 cm. Corn cultivation was based on crop guideline from Rural Development Administration (RDA). Soil texture was sandy loam. The experimental design of this study was a randomized split plot design with three replications. The treatments were consisted of cow compost (CC), pig compost (PC), aerobic digestate (AD) of swine waste, and biochar cooperation. Fertilizers were applied with 190-39-221 kg·ha^{-1} (N-P_2O_5-K_2O) as whole basal application for P_2O_5 and K_2O, and it was especially applied half for basal at 3 day before sowing and half for additional application for nitrogen, based on chemical properties of soil before experiment. PC and CC were applied with 25,000 and 5500 kg·ha^{-1} into soil, recommended application rates based on chemical properties before experiment, respectively. AD was applied with 100 ton ha^{-1} in soil that was 16%

of water holding capacity. Application rate of biochar cooperated with soil was 1 % of soil weight (1,300,000 kg·ha^{-1}) [18]. Biochar from rice hull was purchased from local farming cooperative society. Chemical properties of soil used were presented in **Table 1**.

Soil samples were periodically collected for 15 days after treatment during corn cultivation periods. The samples were dried and passed through 2 mm sieve and then stored in refrigerator (4˚C) until analyzing the soil chemical properties.

Analytical soil chemical properties were total nitrogen (TN), total carbon (TC), total organic carbon (TOC) and total inorganic carbon (TIC) by TOC analyzer (Elementar Vario EL II, Germany). Total carbon combustion temperature was 950˚C and WO_3 was used as the catalyst. The carbonate was destroyed completely by using 2 M HCl until there were no bubbles and fumes, and then samples were dried for another analysis. Consequently, TOC content was obtained. Total inorganic carbon (TIC) was determined by the difference between TC and TOC.

The soil carbon sequestration by biochar application is determined by the soil carbon residual differences between compost treatments only and cooperated with biochar after harvesting corn. The following equation was used:

$$SS_{TC} = \left(T_{TC}i - NT_{TC}i\right) * SW \quad (1)$$

SS_{TC} = Sequestration of soil carbon (kg·ha^{-1}).
T = Treatment of organic composts and cooperated with biochar.
NT = Non-treatment of pig composts only.
i = Date of last measurement of soil carbon analyzed.
SW = Soil weight (kg·ha^{-1}).

The reduction of greenhouse gas emissions was estimated by using Equation (2) as follow:

$$CO_2 - e = SS_{TC} \times CF_{sc} \quad (2)$$

SS_{TC} = Sequestration of soil carbon (kg·ha^{-1}).
CF_{sc} = Conversion factor of CO_2 emission from soil carbon.

3. Results and Discussions

3.1. Chemical Properties of Input Materials

For investigating TC contents of input materials, its biochar was higher at 2.1 times than PC. Biochar could be mostly organic carbon as well as its PC due to carbon fractions (**Table 2**). However, biochar could be mostly non-degradable organic carbon on the contrary of its PC because it resists microbial decomposition in the soil for a much longer time than regular biomass [11]. Additionally, biochar's carbon bonds can't be broken down, and remain in soil for centuries [19]. Lowest TC content was observed to be its CC. For nitrogen contents of input materials, TN content of PC was highest at 1.5% (**Table 2**). Furthermore, TC contents of biochar were increased at 19.7% and 1.5 times when compared with original material, rice hull.

Table 1. Physiochemical properties of soil used in this study.

Soil type	pH (1:5)	EC (dS/m)	T-C (g/kg)	T-N (g/kg)	Av.P_2O_5 (mg/kg)	Ex. Cation (cmol$^+$/kg)		
						K	Ca	Mg
Sandy loam	6.2	3.5	11.8	5.8	234	0.15	4.20	1.11

Table 2. Soil carbon fractions and total nitrogen contents of input materials.

Input materials*	TC	TOC	TIC	TN
	---------------------------%---------------------------			
CC	27.1 ± 0.2	26.6 ± 0.2	0.33	1.1
PC	41.5 ± 0.2	34.8 ± 0.4	6.7	1.5
Rice hull	36.7 ± 0.4	-	-	0.37 ± 0.03
Biochar based rice hull	56.4 ± 0.1	55.2 ± 0.4	1.15	-

*CC; cow compost, PC; pig compost.

3.2. Changes of Soil Total Carbon and Organic Carbon Contents with Different Organic Composts and Cooperated with Biochar Application

Changes of TC and TOC contents with different organic composts and cooperated with biochar in the sandy loam soil during corn cultivation periods were described in **Figure 1**. Soil total carbon contents were decreased from 15 days after sowing and then maintained the stage state from 75 days after sowing periods through the harvesting periods except PC + 1% biochar application. It was decreased from 30 days after sowing through corn cultivation periods in PC + 1% biochar treatment. Soil organic matter (SOM) content is a balance between addition and decomposition rates (turnover rates). The key to sustain productivity of agricultural system is the maintenance of SOM levels and nutrient cycling. However, its PC + 1% biochar treatment could be mostly non-degradable organic carbon on the contrary of its CC because it resists microbial decomposition in the soil for a much long time. For the organic carbon contents, it was appeared to be highest in PC + 1% biochar treatment. However, it was observed that the changing patterns of organic carbon contents (<1%) were similar to their total organic carbon contents (>1%).

3.3. Soil Carbon Sequestration, CO_2-E Emission Reduction and Profit Analysis with Different Organic Composts and Cooperated with Biochar Application

Soil carbon sequestration with TC for different organic composts and cooperated with biochar in the sandy loam soil during corn cultivation periods was estimated by using Equation (1) (**Table 3**). It was estimated that soil carbon sequestration by AD, CC and PC + 1% biochar application was estimated to be 429 kg·ha^{-1}, 2366 kg·ha^{-1}, and 3978 kg·ha^{-1}, respectively, in sandy loam soil.

In 2008, prices of traded CO_2 offsets on the Chicago Climate Exchange were volatile, ranging from $1 to $7.40 MT CO_2 [15]. During the same year, the market prices of CO_2 offsets in the European Climate Exchange varied between $17 and $31 MT CO_2 [16]. Therefore, for estimating the value of potential CO_2 offset, a low and high value of $1 and $31 MT CO_2 was used, assuming a carbon trading mechanism exists for biochar application in the agricultural practices. Furthermore, the market price CO_2 in KCX recently traded about $7.9 per 1 Korean Allowance Unit (KAU) on January 12, 2015. CO_2-*e* emission reduction was calculated by using Equation (2) based on soil carbon sequestration in the corn fields cooperated with different organic composts and biochar (**Table 3**). It was estimated that CO_2-*e* emission reductions of AD, CC and PC + 1% biochar were 0.16 MT CO_2 ha^{-1}, 0.87 MT CO_2 ha^{-1} and 14.58 MT CO_2 ha^{-1}, respectively. And profitability by each treatment was 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 + 1% biochar per hectar during corn cultivation (**Table 3**). However, it was estimated that the market prices of CO_2 in corn cultivation with AD, CC and PC + 1% biochar were $1.26, $6.87 and $115.20 per hectar, respectively, in KCE (**Table 3**). It was appeared that the price of CO_2 per hectar for corn cultivation with PC + 1% biochar was

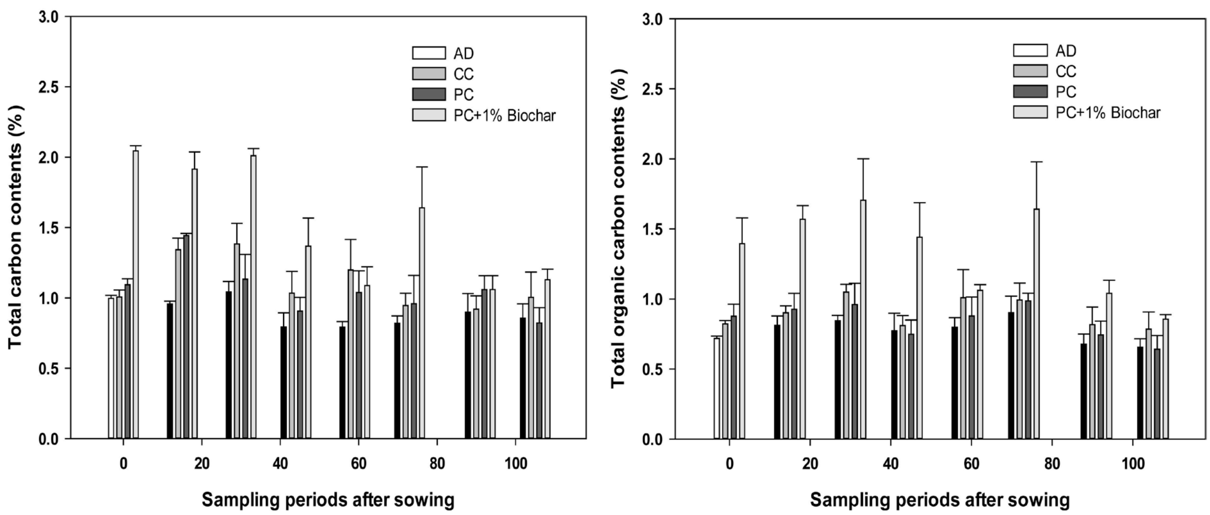

Figure 1. Changes of TC contents with different application rates of biochar in the sandy loam soil applied during corn cultivation periods (AD; aerobic digestate, CC; cow compost, PC; pig compost).

high at 16.8 times relative to the cow compost treatment only (**Table 3**). It was observed that the CO_2 price in KCX is actually similar to \$66.60 MT ha^{-1} of 0.2% biochar cooperated with CC into clay loam soil which was biannual experiment (unpublished data). Therefore, the profitability cooperated with biochar could be benefited for crop cultivation in case of carbon trading under clean mechanism development (CDM) for agricultural practices.

3.4. Corn Growth Responses to Different Compost and Cooperated with Biochar Application

Responses of corn growth and yield to different organic composts and cooperated with PC + 1% biochar were shown in **Table 4**. It was appeared that plant height and fresh yield were not significantly different among the treatments relative to the application plot of pig compost alone. It was determined that application of biochar in the corn field for carbon sequestration was significantly not occurred the damage of corn growth. Whether biochar will ultimately benefit plants by providing nutrient or inhibit plant growth by sequestering them is still an open question. Shin *et al*. [17] [18] reported that plant height and fresh weight were not significantly different between application plots of organic composts and plots cooperated with biochar. In the other hand, declines in plant growth in some experiments with biochar has been attributed a decline in available ammonium [19].

4. Summary

The quantitative analyses focus on using biochar as its carbon sequestration and greenhouse gas emission reduction benefits for agricultural uses. It was estimated that soil carbon sequestration by AD, CC and PC + 1% biochar application was estimated to be 429 kg·ha^{-1}, 2366 kg·ha^{-1}, and 3978 kg·ha^{-1}, respectively, in sandy loam soil.

It was estimated that CO_2-*e* emission reductions of AD, CC and PC + 1% biochar were 0.16 MT CO_2 ha^{-1}, 0.87 MT CO_2 ha^{-1} and 14.58 MT CO_2 ha^{-1}, respectively. And profitability was 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 + 1% biochar per hectar during corn cultivation. However, it was estimated that the market prices of CO_2 in corn cultivation with AD, CC and PC + 1% biochar were \$1.26, \$6.87 and \$115.20 per hectar, respectively, in KCX.

For plant responses, it was determined that application of biochar in the corn field for carbon sequestration was significantly not occurred the damage of corn growth. However, addition of biochar with organic composts could have a potential soil C sequestration in agricultural practices. For the future study, application of pellet form of biochar with organic compost in agricultural land need to be more elucidated soil C sequestration in practice with labor save and reduction of non point contaminant.

Table 3. Carbon sequestration, CO_2-*e* emission reduction and profit analysis with different composts and cooperated with biochar application in sandy loam soil during corn cultivation periods.

Treatments*	Carbon sequestration (kg·ha^{-1})**	CO_2-*e* emission reduction (MT ha^{-1})	Profit(\$ ha^{-1})		
			\$1/MT CO_2	\$7.9/MT CO_2	\$31/MT CO_2
AD	429	0.16	0.16	1.26	4.96
CC	2,366	0.87	0.87	6.87	26.97
PC + 1% biochar	3,978	14.58	14.58	115.20	451.98

*AD; aerobic digestate, CC; cow compost, PC; pig compost. **1 kg C = 3.664 kg CO_2-*e*.

Table 4. Responses of plant growth and yield to different organic composts and cooperated with biochar for corn cultivation.

Treatments*	Plant height (cm)	Fresh yield (kg·ha^{-1})	Fresh biomass weight (kg·ha^{-1})
AD	177.6 ± 7.3	12,226 ± 245	59,858 ± 3857
CC	184.9 ± 4.4	12,915 ± 201	64,259 ± 6072
PC	184.2 ± 2.1	12,599 ± 269	66,421 ± 9899
PC + 1% Biochar	188 ± 2.4	12,484 ± 263	68067 ± 1475

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

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