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Original paper

Estimation of Carbon Sequestration and Its Profit Analysis with Different Application Rates of Biochar during Corn Cultivation Periods

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옥수수 재배기간 동안 바이오차 시용 수준에 따른 탄소 격리량 산정 및 이익 분석

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ABSTRACT: Despite the ability of biochar to enhance soil fertility and to mitigate greenhouse gas, its carbon sequestration and profit analysis with arable land application have been a few evaluated. This study was conducted to estimate carbon sequestration and to evaluate profit of greenhouse gas mitigation during corn cultivation periods. For the experiment, the biochar application rates were consisted of pig compost(non application), 2,600(0.2%), 13,000(1%), and 26,000(2%) kg/ha based on pig compost application. For predicting soil carbon sequestration of biochar application, it was appeared to be linear model of Y = 0.5523X - 742.57 (r^2 = 0.939**). Based on this equation, soil carbon sequestration by 0.2, 1 and 2% biochar application was estimated to be 1,235, 3,978, and 14,794 kg/ha, and their mitigations of CO_2-eq. emissions were estimated to be 4.5, 14.6, and 54.2 ton/ha, respectively. Their profits were estimated at $14.6 for lowest and $452 for highest. In Korea Climate Exchange, it was estimated that the market price of CO_2 in corn cultivation periods with 0.2, 1 and 2% biochar application was $35.6, $115.3 and $428.2 per hectare, respectively. 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.

Keywords: Biochar, Compost, Greenhouse gas mitigation, Soil carbon sequestration

초 록: 바이오차 시용이 토양비옥도나 온실가스 완화에 기여하는 것 외에, 경작지 시용에 따른 탄소격리 및 순익 분석이 평가된바 거의 없다. 본 연구는 옥수수 재배 기간 동안 온실가스 완화에 대한 이익을 평가하고, 탄소격리를 산정하기 위해 수행되었다. 본 실험의 처리구는 돈분처리구, 돈분을 퇴비로 시용하면서 바이오차 처리를 2,600(0.2%), 13,000(1%), 및 26,000(2%) kg/ha로 나누어 시용하였다. 바이오차 시용에 따른 탄소 격리량을 예측하기 위해 Y = 0.5523X - 742.57 (r^2 = 0.939**) 일차 모형식을 유도하였으며, 본 수식을 바탕으로 바이오차 0.2, 1 및 2% 시용 시 탄소 격리량은 각각 1,235, 3,978, 및 14,794 kg/ha로 산정되었고,

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온실가스 완화는 각각 4.5, 14.6, 및 54.2 ton/ha로 평가 되었다. 이에 대한 이익 평가는 적게는 $14.6, 많게는 $452로 산정되었다. 또한 한국 기후변화 시장의 이산화탄소 시장 거래가로는 바이오차 0.2, 1 및 2% 시용 시 $35.6, $115.3 및 $428.2로 나타났다. 바이오차 시용에 대한 작물 재배에 있어, 초장과 수량은 처리간에 유의차가 인정되지 않았다. 따라서 본 실험결과는 농사활동에서 바이오차를 토양에 시용함으로서 탄소 배출건 거래제가 시행된다는 전제 조건하에 기초자료가 될 것이다.

주제어: 바이오차, 퇴비, 온실 가스 완화, 토양 탄소 격리

1. Introduction

Global warming is becoming a critical issue around the world. Numerous researchers and organizations have been involved in mitigating the greenhouse gases from various sources[1),2),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[3),4)]. Biomass is composed of carbon rich materials including all plants, animals, nutrients, excrements and bio-waste from households and industries[5)]. Unused or discarded biomass residues from agricultural areas have a 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 =1018 joules) out of a total 70 EJ[6)]. 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[7)]. The interest in 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[8)].

Soil plays significant roles in global carbon cycle. It was estimated that soils have contributed as much as 55 to 878 billion tons (GT) of carbon to the total atmospheric CO_2[9),10)]. 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[11)]. 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 was used[12),13)], assuming a carbon trading mechanism exists for bio-char application in the agricultural practices.

For effect of biochar application, when biochar from rice hulls was cooperated with sandy loam soil (0.2% of soil weight), applications of aerobic swine digestate, cow compost, and pig compost could sequester C by 38.9, 82.2 and 19.7% in soil, respectively[14].

Therefore, this experiment was conducted to estimate the carbon sequestration and its profit analysis, especially for total carbon in soil cooperated with pig compost and different ratios of biochar during corn cultivation periods.

2. Materials and Methods

The corn variety used in this biannual experiment was Miback 2 Ho, and planting distance was 30×60 cm. 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 pig compost (PC) application only, 0.2, 1 and 2% of biochar application rates of soil weight (2,600, 13,000, and 26,000 kg/ha). Fertilizers were applied with 190-39-221 kg/ha ($N-P_2O_5-K_2O$) 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 was applied with 25,000 kg/ha in to soil. Chemical properties of soil used were presented in [Table1].

Biochar from rice hull was purchased from local farming cooperative society. 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℃) 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 temperatures was 950℃ and WO_3 was used as the catalyst. The carbonate was destroyed completely by using 2M HCl until there were no bubbles and fumes, and then samples were dried for another analysis. Thus TOC content was obtained. Total inorganic carbon (TIC) was determined by the difference between TC and TOC.

For estimating soil carbon sequestration by biochar application, it is determined by the soil carbon residual differences between compost treatments only and cooperated with biochar after harvesting corn. The equation was follow;

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

SS_{TC} = Sequestration of soil carbon
T = Treatment of agricultural organic resources with biochar
NT = Non-treatment of biochar with agricultural organic resources
i = date of last measurement of soil carbon analyzed
SW = Soil weight

And mitigation of greenhouse gas was also estimated by using Eq. (2) as follow;

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

SS_{TC} = Sequestration of soil carbon
CF_{SC} = conversion factor of CO_2 emission from soil carbon

Table 1. Physiochemical Properties of Soil used in this Study

Soil type	pH (1:5)	EC[1] (dS/m)	TC[2] (g/kg)	TN[3] (g/kg)	Av.P_2O_5 (mg/kg)	Ex.Cation ($cmol^+$/kg)		
						K	Ca	Mg
Sandy loam	6.19	3.51	11.83	5.8	234	0.15	4.20	1.11

[1]EC; Electrical conductivity, [2]TC; Total carbon, [3]TN; Total nitrogen

3. Results and Discussions

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[6]. Also, biochar's carbon bonds don't break down, and remain in soil for centuries[15]. Lowest TC content was observed to be its PC. 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.

3.1. Soil carbon sequestration with different application rates of biochar

Changes of TC contents with different application rates of biochar in the sandy loam soil during corn cultivation periods were described in [Fig. 1]. Soil carbon contents were decreased from 30 days after sowing, and then maintained the stage state through the harvesting periods except 1 and 2% of application rates.

Soil carbon sequestration with TC for different application of biochar in the sandy loam soil during corn cultivation periods was estimated by using Eq. (1)([Fig. 2]). Based on the observed data from field trial, an estimated soil carbon sequestration model was derived to be Y = 0.5523X – 742.57. It shown that the relationship among application rates of biochar and carbon sequestration was significantly a positive linear (r^2 = 0.9392**) ([Fig. 2]). It was estimated that

Table 2. Soil Carbon Fractions and Total Nitrogen Contents of Input Materials

Input materials	TC[1)]	TOC[2)]	TIC[3)]	TN[4)]
	%			
PC[5)]	27.1 ± 0.2	26.6 ± 0.2	0.33	1.5
Rice hull	36.7 ± 0.41	–	–	0.37 ± 0.03
Biochar based rice hull	56.4 ± 0.1	55.2 ± 0.4	1.15	–

1)TC; Total carbon, 2)TOC; Total organic carbon, 3)TIC; Total inorganic carbon,
4)TN; Total nitrogen, 5)PC; Pig compost

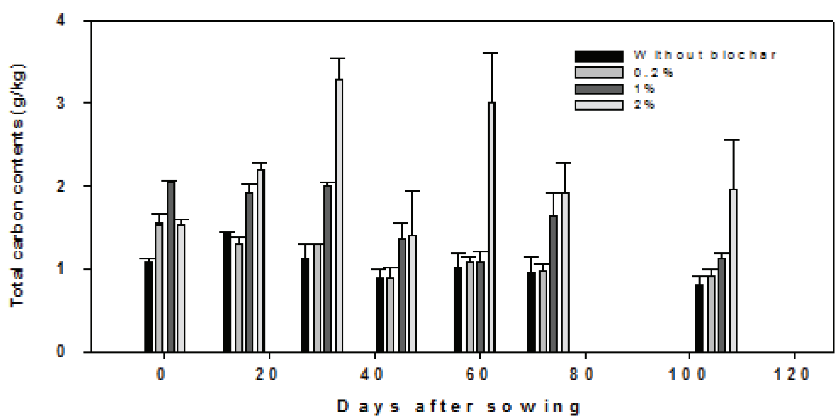

Fig. 1. Changes of total carbon contents with different application rates of biochar in the sandy loam soil applied during corn cultivation periods.

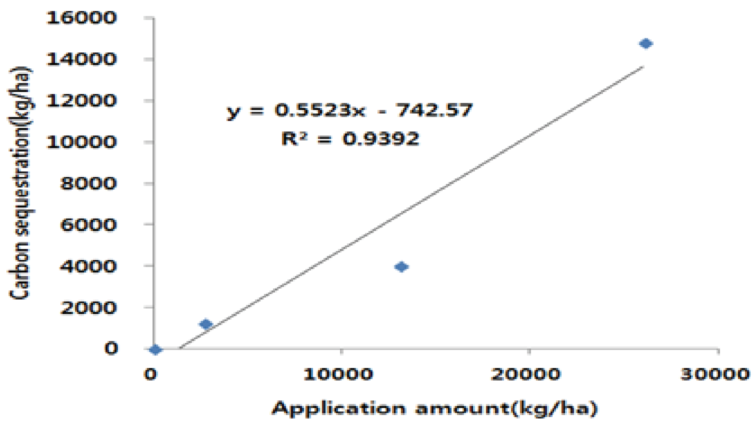

Fig. 2. Relationship between application rates of biochar and carbon sequestration during corn cultivation.

soil carbon sequestration and recovery rates were 3,978 kg/ha and 54.3%, respectively, when 1% biochar applied into sandy loam soil. However, when biochar from rice hull is cooperated with clay loam soil (0.2% of soil weight), applications of anaerobic swine digestate, cow compost, and pig compost can sequester C by 38.9, 82.2 and 19.7% in soil, respectively[14].

In 2008, prices of traded CO_2 offsets on the Chicago Climate Exchange were volatile, ranging from \$1 to 7.40/MT CO_2[12]. During the same year, the market prices of CO_2 offsets in the European Climate Exchange varied between \$17 and \$31/MT CO_2[13]. 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 Korean Climate Exchange recently traded about \$7.9 per 1 Korean Allowance Unit (KAU) on January 12, 2015. Mitigation of CO_2–eq. emission was calculated by using Eq. (2) based on soil carbon sequestration in the corn fields cooperated with different application rates of bio–char ([Fig. 2]). It was estimated that mitigation of CO_2–eq. emission by each biochar application rates was 4.5, 14.6 and 54.2 MT/ha, respectively ([Table 3]). And profitability of 2% bio–char application was also estimated to be \$54.2 for lowest and \$1,680.2 for highest per hectare during corn cultivation. However, it was estimated that the market price of CO_2 in corn cultivation with 0.2, 1 and 2% biochar application was \$35.6, \$115.3 and \$428.2 per hectare, respectively, in Korean Climate Exchange ([Table3]). These results had been some

Table 3. Profit Analysis and Mitigation of CO_2-eq. Emission with different Application Rates of Biochar in Sandy Loam Soil during Corn Cultivation

Application rate of biochar (kg/ha)	CO_2–eq. reduction (MT/ha)	Profit (\$/ha)		
		\$1 per MT CO_2	\$7.9 per MT CO_2	\$31 per MT CO_2
2,600	4.5	4.5	35.6	139.5
13,000	14.6	14.6	115.3	452.6
26,000	54.2	54.2	428.2	1,680.2

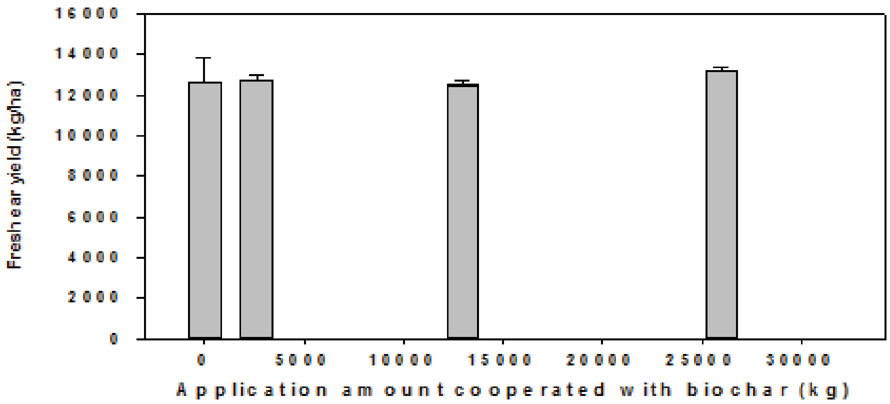

Fig. 3. Effect of fresh ear yield on different biochar application rates after corn harvest.

agreements with previous research that mitigation of CO_2-eq. emission of AD, CC and PC + 1% biochar were 0.16, 0.87 and 14.58 MT CO_2/ha, 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 hectare during corn cultivation[16].

Effects of fresh ear yield to different application rates of biochar were shown in [Fig. 3]. It was appeared that fresh ear yield was not significantly different among application rates 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. However, Shin *et al.*(2014)[14] 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[17].

4. Conclusion

The quantitative analyses focus on using biochar as potential carbon sequestration for agricultural uses. Based on the observed data from field trial, an estimated soil carbon sequestration model was derived to be Y = 0.5523X - 742.57 (r^2 = 0.939**). The relationship between application rates of biochar and carbon sequestration was significantly a positive linear. It was estimated that soil carbon sequestration and recovery rates were 3,978 kg/ha and 54.3%, respectively, when 1% biochar applied into corn field which is sandy loam soil. It was estimated that mitigation of CO_2-eq. emission was 4.5 for 0.2% biochar, 14.6 for 1% biochar, and 54.2 MT/ha for 2% biochar. And profitability of 2% biochar application was also estimated to be $54.2 for lowest and $1,680.2 for highest per hectare during corn cultivation. In Korea Climate Exchange, it was estimated that the market price of CO_2 in corn cultivation with 0.2, 1 and 2% biochar application was $35.6, $115.3 and $428.2 per hectare, respectively.

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.

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