Carbon Sequestration Potential Of Soils Applied With Biochar Utilizing Different Agricultural Waste Materials

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Abstract: Biochar is widely recognized as an efficient tool for carbon sequestration and improves soil fertility. Biochar addition to soils potentially affects various soil properties, and these effects are dependent on biochars derived from different feedstock materials and pyrolysis processes. The study was conducted to compare the chemical composition of biochar from different materials and investigate the effects of amendment on soil carbon sequestration potential and on the growth and biomass yield of corn. A selection of agricultural waste materials with different characteristics (sawdust, dried banana leaves, cacao pods, tobacco stalks and coconut shells) were pyrolyzed at about 250˚C in order to optimize the physicochemical properties of biochar as a soil amendment. An efficacy test of biochar at 5 tons ha^{-1} on corn for 60 days in a pot experiment was undertaken. The biochar have neutral to alkaline pH which range from 7.9 to 8.2, with NPK levels considerably low at 1.93 to 3.50 percent but contain Cu, Zn, Mn and Fe, and other micronutrients. The C:N ratio range from 11.59 to 11.61 g C g^{-1} N indicating that soil organic matter fractions from biochar are low in C and high in nitrogen. Biochar addition significantly enhanced the height growth and biomass yield of corn. Soil organic matter and organic carbon contents are high with average values of 13.76% and 79.80 g kg^{-1} soil, respectively. The significant amount of CO_2 sequestered by soils applied with biochar averaged at 64.40 Mg CO_2 ha^{-1} confirms that biochar is an efficient sink of CO_2. There is a need for further study in order to find the conditions that support CO_2 sequestration by biochar amendment. It should be noted that the results described in the study were derived from a one-time soil sampling, hence, the need for another study to arrive at a more reliable and accurate carbon sequestration potential estimates.

Index Terms: biochar, carbon sequestration, carbon stock, feedstock, pyrolysis, soil physical properties,

1 INTRODUCTION

The Philippine Organic Agriculture Act (RA 10068) was approved to promote and implement the practice of organic agriculture in the Philippines that will cumulatively condition and enrich the fertility of the soil, increase farm productivity, reduce pollution and destruction of the environment. Incorporation of organic amendments to a problem soil is an essential management strategy for enhancing the restoration of degraded soils and providing better soil environment to below- ground soil microorganism and above-ground plant community. Results of research studies revealed that continuous use of organic fertilizers increased soil organic matter, reduced erosion, better water infiltration and aeration, higher soil biological activity, and increased crop yields after a year of application due to residual effects. Organic fertilizers have been known to improve biodiversity and long-term productivity of soil, and may prove a large depository for excess carbon dioxide. Organic nutrients increased the abundance of soil organisms by providing organic matter and micronutrients for organisms such as fungal mycorrhiza. The benefits derived from organic fertilizers, the existence of available raw materials within the locality and the high costs of chemical fertilizers favour the manufacture of quality organic fertilizers. Biochar is a charcoal used as a soil amendment. Like most charcoal, biochar is made from biomass via pyrolysis. Independently, biochar can increase soil fertility of acidic soils (low pH in soils), increase agricultural productivity, and provide protection against some foliar and soil-borne diseases. Furthermore, biochar is a stable solid, rich in carbon, and can endure in soil for thousands of years. Due to the high stability of carbon in biochar that added to soil may act as a carbon sink and might be part of a solution to the global warming problem by reducing the concentrations of carbon dioxide (CO2) in the atmosphere. The type of feedstock material is an important factor that determines the final application of the biochar and its effect in soil, because its properties are affected by the nature of the original material. Hence, this study. Objectives: This study was undertaken to investigate the chemical composition of biochar produced from the different waste materials, to assess the efficacy of biochar as organic amendment in corn, and to evaluate the organic carbon sequestered from the soils applied with biochar.

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2 MATERIALS AND METHODS

Biochar Preparation from Agricultural Residues

Biochar was produced via pyrolysis (250^0C) using various agricultural wastes as substrates such as sawdust, dried banana leaves, cacao pods, tobacco stalks and coconut shells. These organic amendments were brought to the Regional Soil Analytical Laboratory, for analysis of pH, organic matter content, available phosphorus and exchangeable potassium.

Soil Collection and Analysis

A loam soil was collected in Annapunan, Echague, Isabela. A 10-kg of soil was placed in polyethylene bags (10 in X 17 in). Each treatment has 10 sample plants. Polyethylene bags with soil were placed in a green house. A composite sample of the soil used in the pot experiment was brought at the Regional Soil Analytical Laboratory, Tuguegarao City for analysis of NPK content and pH of the soil as a basis for fertilizer recommendation. In addition, soil samples were presented for the plate counts of the microbial content of the soil at the Crop Protection Laboratory of College of Agriculture at Isabela State University, Echague, Isabela.

Experimental Design and Treatments

The experiment was arranged in Completely Randomized Design (CRD) with three replications. The biochar was applied at 5 tons ha^{-1} along with the recommended rate of inorganic fertilizer (140- 60 -0 NPK ha^{-1}) was used. The treatments were as follows: T_1- RR, T_2- Sawdust (5 tons/ha^{-1}); T_3- Banana Leaves (5 tons/ha^{-1}); T_4- Cacao Pods (5 tons/ha^{-1}); T_5- Tobacco Stalks (5 tons/ha^{-1}) and T_6- Coconut Shells (5 tons/ha^{-1}).

Planting and Care and Management

The corn seeds were sown at the rate of two seeds per polyethylene bag and covered with thin soil and hand-pressed in order to ensure soil-seed contact to enhance/ have uniform germination. Thinning was done at 10 days after seedling emergence to maintain one healthy plant per polyethylene bag. Replanting was done if ever there was mortality among the experimental plants. Watering the plants was done as the need arose. Insect pest was controlled by monitoring and manual picking to avoid severe infestation.

Data Gathered

The chemical properties of soil were recorded before and after the conduct of the study. The microbial plate count analysis was done on different agricultural waste materials. Plant height of corn was measured at 30 and 60 gays after planting, while biomass yield (60 DAP) by getting the weight of the whole plant. The sequestered CO_2 equivalent will be calculated using the equation: $W= 3.67\ [(SOC)\ (D_B \times d_S \times 10{,}000\ m^2)]$ where, SOC = soil organic carbon; Db = bulk density; and ds = soil depth. All the data gathered were analyzed using the Analysis of Variance (ANOVA) for Complete Randomized Design (CRD). Means were compared using the Duncan's Multiple Range Test (DMRT) if the result of any parameter is significant (Gomez and Gomez, 1984).

3 RESULTS AND DISCUSSION

Nutrient Composition of Biochar

The biochar derived from tobacco stalks showed the highest organic carbon with 9.16% followed by cacao pods and dried banana leaves both with mean organic carbon content of 7.08 %. Lowest organic carbon was observed in sawdust with 1.97%. The presence of large quantities of organic carbon in a compost helps improve the physical and chemical properties of soils. There is no significant variation on the NPK content of the five biochar products. The NPK levels are considerably low if compared to chemical fertilizer with mean values of 0.52 % N; 0.95 % P, and 1.16 % K. However, the five biochars contain wide range of plant nutrients that are essential for crop growth which are not available in chemical fertilizers. Total NPK of the five composts ranged from 1.93 to 3.50 lower than the 5% required for a material to be considered organic (PNS for Organic Fertilizer). The biochar derived from tobacco stalks and cacao pods had the highest with 3.50 and 2.89, respectively. The C/N ratio of the products is 11.60. The ratio below 20 is indicative of an acceptable maturity of the final products, a ratio of 15 or even less is preferable (Inbar et al, 1990). The C:N ratio in all the treatments were narrow which ranged from 11.59 to 11.61 g C g^{-1} N. This indicates that the biochar and resulting soil organic matter fractions were low in C and high in N. The total quantity of biomass produced by the biochar, its C:N ratio, and how it is managed will determine how much soil organic matter is likely to increase. Organic amendments with low C:N ratio will decompose faster than residue with a high C:N ratio. Table 1b shows that compost contains Cu, Zn, Mn and Fe, and probably contains a number of other micronutrients which were not included in the analysis. These micronutrients are not present in the ordinary formulations of inorganic fertilizer sold in the market.

Table 1a. *Chemical Composition of Biochar derived from (5) Five Agricultural Waste Materials*

BIOCHAR	MC	OM	OC	N	P	K	NP	C:N
	%	%	%	%	%	%	K	
Sawdust	*20.00*	*3.40*	*1.97*	*0.17*	*0.78*	*0.98*	*1.93*	*11.59*
Banana Leaves	*21.00*	*12.20*	*7.08*	*0.61*	*0.81*	*1.05*	*2.47*	*11.61*
Cacao Pods	*19.80*	*12.20*	*7.08*	*0.61*	*0.92*	*1.36*	*2.89*	*11.61*
Tobacco Stalks	*23.00*	*15.80*	*9.16*	*0.79*	*1.13*	*1.58*	*3.50*	*11.59*
Coconut Shells	*25.00*	*8.80*	*5.10*	*0.44*	*1.13*	*0.82*	*2.39*	*11.59*

Table 1b. *Chemical Composition of Biochar derived from (5) Five Agricultural Waste Materials*

BIOCHAR	Zn	Cu	Mn	Fe
	ppm	ppm	ppm	ppm
Sawdust	*0.19*	*0.10*	*0.50*	*1.69*
Banana Leaves	*0.12*	*0.01*	*1.47*	*2.47*
Cacao Pods	*0.03*	*0.01*	*0.33*	*2.92*
Tobacco Stalks	*0.18*	*0.15*	*2.34*	*7.53*
Coconut Shells	*0.11*	*0.16*	*3.32*	*4.45*

Microbial Count

Microbial plate count analysis was done on different agricultural waste materials. It was found that they differ from each other in terms of the total number of microorganism. Soil microorganisms play a crucial role in the carbon sequestration process by transforming plant residues into smaller carbon molecules that are more likely to be protected and sequestered (Six et al., 2006).This serves as the basis whether the biochar had enhanced the biological activities of the microorganisms present in the different agricultural waste materials used. The total number of microorganisms present in Potato Dextrose agar differed in Nutrient Agar. The colors of the different biochar from waste materials greatly influenced the biological activities of the microorganisms. It also serves as the storehouse for food of microorganisms. Microbial count ranged from 7.6×10^6 to 7.1×10^7 cfu/ ml for bacteria; and 3.7×10^5 to 7.9×10^5 cfu/ml for fungi. Soil fungi and bacteria play an important role in processing soil organic matter and soil carbon sequestration by maximizing the amount of carbon allocated to the soil and producing compounds that improve aggregate stability. These decomposition processes are essential to maximizing biomass production and ensuring that carbon is converted into stable forms that remain protected in soil (Six et al., 2006).

***Table 2**. Microbial Count in Soils applied with biochar Derived from Different Agricultural Waste Materials*

Substrates	No. of Colony Forming Units (CFU/ml)	
	Bacteria	Fungi
Sawdust	4.9×10^7	7.7×10^5
Banana Leaves	7.1×10^7	3.7×10^5
Cacao Pods	3.6×10^7	4.7×10^4
Tobacco Stalks	7.6×10^6	5.3×10^5
Coconut Shells	8.0×10^6	7.9×10^5

Efficacy test of Biochar on Corn

Table 3 shows the result of efficacy test of biochar on hybrid corn for 60 days. Biochar significantly enhanced the growth of the corn plants. Plants applied with biochar are taller than the control plants at 30 and 60 DAP. At 30 days, the plants applied with biochar as nutrient supplement to the recommended rate of inorganic fertilizer (140-30-0 kg) further enhanced the growth of the corn plants as evidenced by the taller crops in T_6 = coconut shells (74.73 cm); T_4 = cacao pods (73.73 cm); T_5 = tobacco stalks (73.63 cm); T_3 = banana leaves (71.97 cm) compared with T_1 which is devoid of biochar (60.07 cm). Although, the plants applied with biochar (sawdust) were comparable to the other plants, it did not vary with the plants solely grown with inorganic fertilizers (T_1). Average height of plants in Treatment 2 is 70.10 cm, while that in Treatment 1 is 60.07 cm. Generally, the plants in T_1 were significantly shorter than those plants with biochar. A similar trend of result was observed after 60 days except that plants with biochar from banana leaves (197.27 cm) and sawdust (191.27 cm) were comparable with the plants without biochar (174.40 cm).

***Table 3**. Height and Biomass Yield of Hybrid Corn applied with Biochar from Different Agricultural Waste Materials*

TREATMENT	Plant Height (cm)		Biomass yield (g/plant)
	30 DAP	60 DAP	
140-60-0 kg NPK ha^{-1}	60.07 b	174.40 b	340.33 c
Biochar (Sawdust)	70.10 ab	191.27 ab	490.00 bc
Biochar (Banana Leaves)	71.97 a	197.27 ab	638.80 ab
Biochar (Cacao Pods)	73.73 a	209.97 a	653.80 ab
Biochar (Tobacco Stalks)	73.63 a	216.93 a	652.67 ab
Biochar (Coconut Shells)	74.73 a	215.13a	707.07 a
Results	**	**	**
C. V. (%)	3.73	3.42	16.52

Result further revealed that average biomass of plant was higher on the crops applied with biochar derived from coconut shells (707.07 g), cacao pods (653.80 g) and dried banana leaves (638.80 g) and tobacco stalks (652.67 g). This indicates that application of biochar derived from these agricultural waste materials can be used as nutrient supplement to inorganic fertilizer to further increase the biomass production of a corn plant. Biochar derived from sawdust (490 g) although comparable to other biochar, showed no additional effect as indicated by the non-significant variation of biomass with plants in Treatment 1 with an average of 340.33 g.

Carbon Content of soils applied with Biochar

Table 4 represents the increment of organic matter content of soils applied with biochar from different agricultural residues. The amount of soil organic carbon in the form of soil organic matter reflects as balance of carbon inputs and carbon losses of organic material (Burke et al. 1989) and factors affecting soil organic carbon include soil type, climate and agricultural management practices. In general, the soil organic matter contents in the soils applied with biochar are very high. It ranged from 11 to 18.60 percent. These average values are higher than 3.4% which is considered the threshold value below which soil function is impaired (Greenland et al., 2004).

***Table 4**. Organic Matter and Organic Carbon Content of Soils applied with Biochar*

BIOCHAR	OM		OC		% OC Increase	CO_2 Eq.
	(%)	g kg^{-1} soil	(%)	g kg^{-1} soil		Mg ha^{-1}
Sawdust	11.60	116	6.73	67.28	41.34	39.4
Banana Leaves	13.80	138	8.00	80.04	68.15	64.8
Cacao Pods	18.60	186	10.79	107.88	126.64	120.6
Tobacco Stalks	11.00	110	6.38	63.80	34.03	32.4
Coconut Shells	13.80	138	8.00	80.04	68.15	64.8
Before addition of biochar	8.22	-	4.76	--	--	--

The average SOC in the soils applied with biochar ranged from 63.80 to 107.88 g kg^{-1} with the highest obtained from soils applied with biochar derived from cacao pods. The lowest is obtained in soil with biochar from tobacco stalks with 63.80 g kg^{-1}. The differences in the SOC could be attributed to the agricultural waste materials used in the production of biochar. The organic carbon in CO_2 equivalent sequestered by the soil applied with biochar were cacao pods (120.6 Mg), dried banana leaves (64.8 Mg), coconut shells (64.8 Mg); then sawdust (39.4 Mg) and tobacco stalks (32.4 Mg). This result represents only the carbon stock and CO_2 from organic matter in the form of soil organic carbon. The significant amount of CO_2 sequestered by the soils indicates the potential and significant CO_2 sequestration of the different with biochar. This study confirms that biochar is an efficient tool for carbon sequestration and shows that it has the substantial role in cleaning the atmosphere from excess carbon dioxide.

4 SUMMARY, CONCLUSION AND RECOMMENDATION

The study was conducted to compare the chemical composition of biochar from different materials and investigate the effects of amendment on soil carbon sequestration potential and on the growth and biomass yield of corn. A selection of agricultural waste materials with different characteristics (sawdust, dried banana leaves, cacao pods, tobacco stalks and coconut shells) were pyrolyzed at about 250˚C in order to optimize the physicochemical properties of biochar as a soil amendment. An efficacy test of biochar at 5 tons ha^{-1} on corn for 60 days in a pot experiment was undertaken. The biochar have neutral to alkaline pH which range from 7.9 to 8.2 with mean of 8.07 described as moderately alkaline. The biochar derived from tobacco stalks showed the highest organic carbon with 9.16 % followed by cacao pods and dried banana leaves both with mean organic carbon content of 7.08 %. The presence of large quantities of organic carbon in a compost helps improve the physical and chemical properties of soils. There is no significant variation on NPK content of the five biochar products. The NPK levels are considerably low if compared to chemical fertilizer which means values of 0.52 % N; 0.95 % P, and 1.16 % K. However, the five biochars contain wide range of the plant nutrients that are essential for crop growth which are not available in chemical fertilizers. Total NPK of the five composts ranged from 1.93 to 3.50 lower than the 5% required for a material to be considered organic (PNS for Organic Fertilizer) with the biochar derived from tobacco stalks and cacao pods the highest with 3.50 and 2.89, respectively. The C/N ratio of the products is 11.60. The ratio below 20 is an indicative of an acceptable maturity of the final products, a ratio of 15 or even less is preferable. The biochar contains Cu, Zn, Mn and Fe, and probably contains a number of other micronutrients which were not included in the analysis. These micronutrients are not present in the ordinary formulations of inorganic fertilizer sold on the market. The total number of microorganisms present in Potato Dextrose agar differed in Nutrient Agar. The colors of the different biochar from waste materials greatly influenced the biological activities of the microorganisms. It also serves as the storehouse for food of microorganisms. The microbial count ranged from 7.6×10^6 to 7.1×10^7 cfu/ ml for bacteria; and 3.7×10^5 to 7.9×10^5 cfu/ml for fungi. Soil fungi and bacteria play an important role in processing soil organic matter and soil carbon sequestration by maximizing the amount of carbon allocated to the soil and producing compounds that improve aggregate stability. These decomposition processes are essential to maximizing biomass production and ensuring that carbon is converted into stable forms that remain protected in soil. Biochar significantly enhanced the growth of the corn plants. Plants applied with biochar are taller than the control plants at 30 and 60 DAP. Likewise, biomass yield were higher on plants applied with biochar derived from cacao pods, tobacco stalks, coconut shells and dried banana leaves. Soil organic matter and organic carbon contents are high with average values of 13.76% and 79.80 g kg^{-1} soil, respectively. The significant amount of CO_2 sequestered by soils applied with biochar averaged at 64.40 Mg CO_2 ha^{-1} confirms that biochar is an efficient sink of CO_2. There is a need for further study in order to find the conditions that support CO_2 sequestration by biochar amendment. It should be noted that the results described in the study were derived from a one-time soil sampling, hence, the need for another study to arrive at a more reliable and accurate carbon sequestration potential estimates.

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