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Potential of Biochar Production from Agriculture Residues at Household Scale: A Case Study in Go Cong Tay District, Tien Giang Province, Vietnam

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ABSTRACT

This study was conducted in Go Cong Tay district (Tien Giang province, Vietnam) to estimate the potential of using residue from rice production, particularly, rice straw, to produce biochar at household scale. The annual rice yield of Go Cong Tay district is 185,072 tons/year. It creates about 233,190 tons of rice straw per year. Currently, most of these residues are open burned by the farmers. This study examined the experimental biochar production in different modes of combustion (6 h, 10 h and 15 h). The results show that 6 h of combustion is the best condition due to high yield of biochar, less ash and low amounts of incompleted biochar. With 100 kg of rice straw sticks, 48.25 ± 2.25 kg of biochar was produced. The amount of ash and incompleted biochar was low, 0.75 ± 0.13 kg and 3.95 ± 1.33 kg, respectively. The thermal energy of biochar from rice straw is about 4,030 kcal/kg, which is higher than other similar materials such as chaff, sawdust, etc. The suggested model of biochar production is compatible with household scale due to the short time of combustion, high productivity and the method is easy to perform. This practice reduces agricultural waste, protects soil and creates useful thermal energy for household activities (e.g., cooking). The ash created from biochar production can be used for fertilizing.

1. INTRODUCTION

Agriculture is one of the main economic activities in Vietnam, especially in rice production. With the two main deltas: Red Reiver delta and Mekong delta, Vietnam is one of the five top countries in rice export (FAO, 2016). Agricultural residue is a concern of developing countries where the rate of residue per productivity is high. In natural conditions, decomposition rate of rice straw is low. There are 6 common practices of rice straw management in Vietnam: open burning, incorporation, mushroom plantation, husbandry feeding, selling and giving to others (Duong and Yoshiro, 2015). Among these practices, burning rice straw is very common in the Vietnam countryside (Duong and Yoshiro, 2015) and it is harmful for the biosphere. Particularly, soil quality might degrade because of high temperature, loss of useful organisms (Mubyana et al., 2007; Tung et al., 2014). It leads to air pollution due to the high concentration of toxic components such as CO_2, CO, CH_4, NO_x, SO_x, $PM_{2.5}$, PM_{10}, PAHs, PCDDs và PCDFs (Mendoza and Samson, 1999; Gadde et al., 2009a; Gadde et al., 2009b). Emission is harmful to the community's health, as well as contributes to climate change and global warming (Danutawat and Oanh, 2007). In addition, the concentration of nutrients in rice straw is high, as reported by Rosmizaet et al. (2012): "25% nitrogen and phosphorus, 50% of sulfur and 75% potassium". So, it is wasteful if these materials are abandoned.

Reproduce is one of the strategies in environment protection. It reduces waste as well as increases the utility of materials. There are several studies and practices on rice straw biochar application for soil treatment or enrichment (Hoang et al., 2013; Ruilun et al., 2013; Mahdi et al., 2016; Nipa et al., 2016; Jin et al., 2016). However, application of biochar as an alternative energy in Vietnam is lacking (Duong and Yoshiro, 2015).

Under the context of lacking energy and the rising awareness of climate change, finding the environmentally friendly source of energy for household activities are needed. In this study, rice straw is used to produce biochar as an alternative energy for cooking at household scale. In order to obtain the research purposes, the potential of using residues and experimental biochar production model are figured out. Go Cong Tay district (Tien Giang province), located in the Mekong delta, was chosen as the study site due to its high area of rice field (99.9% of its crop area is for rice production) and its typical agriculture.

2. METHODOLOGY

2.1 Study site description

Tien Giang province belongs to the Mekong delta, one of the two biggest deltas in Vietnam. It is 70 km from Ho Chi Minh City. Similar to other provinces in Mekong delta, agriculture is the main economic activity of this province, especially rice production, which is divided into 3 crops: Winter-Spring, Summer-Autumn and Autumn-Winter crop.

Go Cong Tay district, located in the East of Tien Giang province (Figure 1), has an area of 18,441.93 ha and a population of 126,804 (TGSO, 2017). It is divided into 13 communes: Vinh Huu, Long Vinh, Long Binh, Binh Tan, Thanh Cong, Yen Luong, Thanh Tri, Binh Phu, Dong Son, Dong Thanh, Binh Nhi, Thanh Nhut and Vinh Binh. The annual yield of staple-food crops is over 322,586.57 ton/year. Rice is the most dominant food crop in Go Cong Tay, followed by corn, watermelon, bean, etc. The total area of rice fields is 32,066 ha (2014) and the average rice yield is 184,700 tons (TGDOARD, 2015).

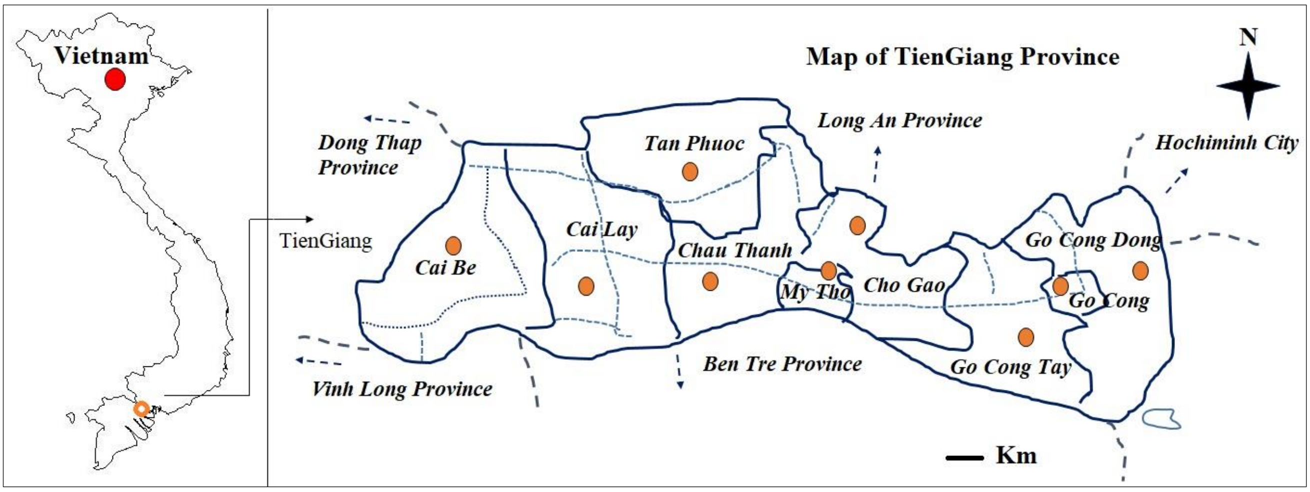

Figure 1. Map of Tien Giang province (TGSO, 2017)

2.2 Estimate emission from rice straw burning

Data is calculated based on the study of Thongchai and Oanh (2011). Emission for burning agricultural residues is estimated by formula (1) and used by Shijian et al. (2009) Thongchai and Oanh (2011); where E_A is the emission of pollutant i from burning plant j, i is the pollutant, j is the plant species, M_j is the burned agriculture residue (kg/year), $EF_{i,j}$: emission coefficient of pollutant i from plant j (g/kg).

$$E_{Ai,j} = \sum M_j \times EF_{i,j} \qquad (1)$$

EF (g/kg) from rice straw is based on the study of Gadde et al. (2009a) as follows: $PM_{2.5}$: 8.3; PM_{10}: 9.1; SO_2: 0.18; CO_2: 1,177; CO: 93; NO_X: 2.28; NH_3: 4.1; CH_4: 9.59; NMVOC: 7.0; EC: 0.51; OC: 2.99.

The biomass yield burned from the plant j (M_j) is estimated by formula (2); where P_j is the plant yield (kg/year), N_i is rate of residues over yield right after harvesting (=1.26), D_j is dry density of residues each year (=0.85), B_j is the rate of burned residues (=82.89%) and η_j combustion productivity (=0.89) (Thongchai and Oanh, 2011).

$$M_j = P_j \times N_i \times D_j \times B_j \times \eta_j \qquad (2)$$

2.3. Field survey and household interviews

The current state of agriculture activities, such as the productivity, yield, amount of residues, etc.

were obtained by interviews. In particular, 120 households (belonging to 3 communes: Vinh Binh, Thanh Nhut, Vinh Huu) took part in the structured interviews by questionnaires randomly (Table 1).

Table 1. Field survey process

No	Communes	Survey sample size (household)	Periods
1	Vinh Binh	40	August-September, 2017
2	Thanh Nhut	40	
3	Vinh Huu	40	

A sampling survey carried out by random method (Cochran, 1977). Sample size formula is determined and followed by Yamane (1976):

$$n = \frac{N}{1+N(e)^2} \quad (3)$$

With N is the Go Cong Tay's population (=126,804), and e is the level of precision (=0.1), the needed sample size called n is 100. In order to increase the confidence level and ensure typical features, the survey was conducted with 120 households.

2.4. Estimate the residues

The field survey was conducted to collect the samples used for estimating the residues. In particular, 3 communes were chosen, named Vinh Binh, Thanh Nhut, Vinh Huu. In each commune, 3 plots (1,000 m^2/plot) were chosen randomly. In each big plot, 5 smaller plots (1 m^2/plot) were taken to collect the biomass as Figure 2. The rice straw is defined as the whole rice plant, excluding its ears and roots.

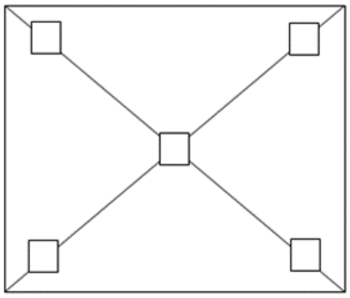

Figure 2. Structure of samples taken

2.5. Biochar production and analysis

Biochar was produced by columniform burner. This burner was made of bricks and mud with the specific dimension as shown in Figure 3. Total utility volume is 0.3276 m^3 including: cylinder (V_1= 0.2826 m^3) and pyramid (V_2= 0.045 m^3).

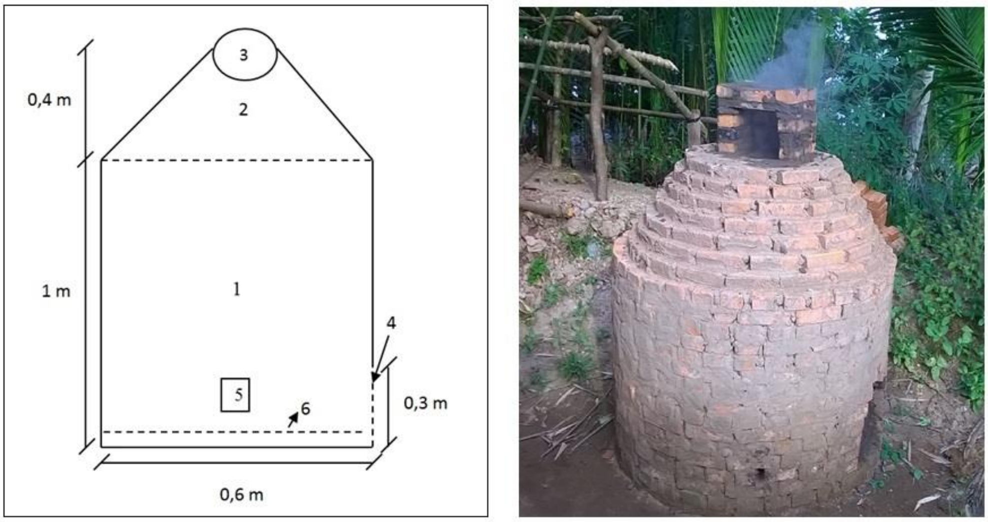

Figure 3. Structure of biochar burner

Regarding the structure of biochar burner, it includes components such as (1) Combustion chamber that contains the ingredients (biomass) (V=0.2826 m^3); (2) Pyramid (V=0.045 m^3); (3) Smoke outlet (round shape, D=0.1 m); (4) Main gate where a fire is lighted and biochar is placed/removed (height=0.3 m and widt = 0.2 m); (5) 4 Ventilations (height=4 cm, width=2 cm); and (6) Steel grate.

Rice straw was compressed into annular sticks with a diameter of 85 mm and a small hole in the center with a radius of 20 mm. The biochar is produced in 3 different combustion modes: 6 h, 10 h and 15 h. The same weight of rice straw sticks (=100 kg) is placed inside the burner. Then, the sticks were started to burn for 5-10 mintutes before closing the gate. Depending on the combustion mode, the area of ventilation was adjusted. In particular, the area of ventilation was 4 cm^2, 2 cm^2 and 1 cm^2 for 6 h, 10 h and 15 h combusting modes, respectively. After the required time (6,10,15 h), these 4 ventilations and the smoke outlet are closed to decrease combustion. When the temperture goes down and the burner is cool naturally, biochar is taken out of the burner.

2.6. Data analysis

The quality of ash was tested by the Center of Technology and Environmental Management, Institute of Biotechnology (Nong Lam University). The quality of biochar was tested and analyzed by Quality assurance and testing center 3 (QUATEST 3, Ho Chi Minh City). The tested parameters include: humidity, ash, sulfur, organic matter and thermal energy. Other social-economic data was analyzed by SPSS (Norusis, 2005). This study used most of common descriptive statistic parameters such as mean, frequency and standard deviation.

3. RESULTS AND DISCUSSION

3.1 Agricultural residues

Rice straw was collected before and after harvesting at 15 sample plots. The results are presented in Table 2. With the average rice yield of 5.76 ton/ha (TGDOARD, 2015), the rate of rice straw over rice yield (per ha) is 7.26/5.76 = 1.26. According to Nam et al. (2014), the average rate of rice straw over rice yield in Mekong delta is 0.92-1.33. Hence, this rate is compatible and acceptable compared to other studies.

Table 2. Estimated weight of rice straw

Plot ($1\ m^2$)	Vinh Binh		Thanh Nhut		Vinh Huu	
	Before harvesting (g)	After harvesting (g)	Before harvesting (g)	After harvesting (g)	Before harvesting (g)	After harvesting (g)
1	1,300	750	1,250	710	1,200	750
2	1,150	700	1,150	720	1,200	730
3	1,300	750	1,300	750	1,150	710
4	1,200	710	1,250	750	1,150	700
5	1,250	730	1,150	710	1,250	720
6	1,150	720	1,250	720	1,300	750
7	1,250	700	1,200	700	1,200	720
8	1,200	700	1,300	700	1,300	750
9	1,150	720	1,250	710	1,250	700
10	1,200	730	1,200	740	1,200	750
11	1,300	730	1,250	740	1,250	740
12	1,250	720	1,150	720	1,200	720
13	1,200	710	1,250	730	1,150	740
14	1,150	700	1,300	740	1,200	740
15	1,200	740	1,300	750	1,200	730
Average	1,217	721	1,237	726	1,210	730

By using that rate, the amount of residues in 13 communes is estimated as presented in Table 3. The annual weight of commercial rice of Go Cong Tay is 185,072 ton/year and the residues are 233,190.72 ton/year. Based on the farmer' interviews, there are 5 ways to deal with rice straw post harvesting. Table 4 presents the usage of these residues. After collecting the ears, rice straw is mostly burned on the field by the farmers (82.89%). They also are buried in soil to enhance the soil quality (18.75%). The remainder are used for feeding cows, planting mushroom or selling, etc.

Table 3. Amount of post-harvesting residues

Name of communes	Winter-Spring crop			Summer-Autumn crop			Autumn-Winter crop			Product (ton/year)	Residues (ton/year)
	Area (ha)	Productivity (ton/ha)	Yield (ton)	Area (ha)	Productivity (ton/ha)	Yield (ton)	Area (ha)	Productivity (ton/ha)	Yield (ton)		
01 Vinh Binh	354	6.8	2,407	354	5.0	1,770	354	4.85	1,717	5,894.1	7,426.57
02 Thanh Nhut	999	7.2	7,190	999.2	5.23	5,230	987	4.95	4,885	17,304.8	21,804.04
03 Vinh Huu	740	6.83	5,057	728	5.14	3,744	710	4.93	3,501	12,302.3	15,500.90
04 Dong Son	690	7.05	4,865	727	5.18	3,765	727	5.01	3,642	12,271.9	15,462.6
05 Binh Phu	906	6.95	6,295	927.3	5.15	4,776	928	5.01	4,648	15,719.2	19,806.2
06 Dong Thanh	1,075	6.66	7,154	1,070.7	5.2	5,567	1,072	5.09	5,455	18,176.3	22,902.14
07 Thanh Cong	538	6.8	3,660	538.2	5.04	2,713	538	4.95	2,664	9,036.7	11,386.24
08 Binh Nhi	898	7.8	7,008	610	5.48	3,343	725	5.2	3,771	14,121.5	17,793.09
09 Yen Luong	682	7.1	4,842	682	5.1	3,478	682	5.0	3,410	11,730.4	14,780.30
10 Thanh Tri	965	6.99	6,741	965	4.89	4,718	965	4.94	4,767	16,226.5	20,445.39
11 Binh Tan	1,012	7.83	7,924	1,022	5.1	5,212	1,012	5.04	5,100	18,236.6	22,978.11
12 Long Vinh	793	7.31	5,794	753	4.92	3,707	780	4.99	3,893	13,394.5	16,877.07
13 Long Binh	1,195	7.23	8,640	1,195	5.15	6,155	1,168	5.02	5,862	20,657.4	26,028.32
Total	10,847	7.15	77,578	10,571	5.12	54,178	10,648	5.01	53,316	185,072	233,190.72

Table 4. Usage of rice straw post-harvesting

Crops	Usage of rice straw post-harvesting (%)					
	Open burn	Feeding cow	Mushroom plantation	Buried in soil	Other (selling, fertilizing, etc.)	Total
Summer-Autumn	73.9	0.8	0.1	25.2	0.01	100
Autumn-Winter	85.29	1.2	1.2	12.3	0.02	100
Winter-Spring	89.5	10	0.45	-	0.042	100
Annual	82.89	12	1.75	18.75	0.072	100

Open rice straw burning is harmful for the biosphere (Danutawat and Oanh, 2007; Zha et al., 2013). Firstly, it destroys the population of useful natural organisms. Secondly, the high temperature leads the soil quality degradation. Soil loses its humidity and other minerals. In addition, the carbon concentration in soil is decreased due to the biomass removal. Thirdly, it creates air emission. The emission is harmful for communities and environment at upper scale, especially in the context of climate change. The emission coefficients are estimated in Table 5.

According to Table 3, the total emission from rice straw buring is 154,025.51 ton/year. The amount of CO_2 is highest 137,961.37 ton/year (accounted for 89.57% of total emission). The amount of CO is 10,900.93 ton/year (accounting for 7.08% of total emission) and the other toxic components such as $PM_{2.5}$, PM_{10}, SO_2, NO_x, NH_3, CH_4, NMVOC, EC, OC accounted for 3.35% in total. As compared to study of Thongchai and Oanh (2011), the share of each parameter is similar to our results. In particular, there are 2 calculations for air emission from residues of rice I and rice II in that study. The ascending order of sharing emission are: CO_2, CO and the others. This similarity might be due to the similar characteristic in weather conditions and agriculture culture between Vietnam and Thailand.

Table 5. Emission from residues burning

Parameters	Emission coefficient (g/kg)	Emmision (ton/year)			
		Winter-Spring crop	Summer-Autumn crop	Autumn-Winter crop	Total
$PM_{2.5}$	8.3	435.96	251.39	285.52	972.87
PM_{10}	9.1	477.98	275.62	313.04	1,066.64
SO_2	0.18	9.45	5.45	6.23	21.13
CO_2	1,177	61,822.56	35,649.44	40,489.37	137,961.37
CO	93	4,884.87	2,816.82	3,199.24	10,900.93
NO_X	2.28	119.75	69.05	78.43	267.23
NH_3	4.1	215.35	124.18	141.04	480.57
CH_4	9.59	503.71	290.46	329.90	1,124.07
NMVOC	7.0	367.67	212.01	240.80	820.48
EC	0.51	26.78	15.44	17.54	59.76
OC	2.99	157.05	90.56	102.85	350.46

NMVOC (Non Methane Volatile Organic Compounds), EC (Element Carbon), OC (Organic Concentration)

3.2 Experimental biochar production and its quality

3.2.1. Biochar production

Biochar is produced from rice straw by burning in different conditions as presented in Table 6. With the same input (100 kg of rice straw sticks), after 6 h of combusting, the amount of biochar product is 48.25 ± 2.25 kg (accounted for 48.25% of the input). The generated amount of ash and incomplete biochar is relatively low, respectively 0.75 ± 0.13 kg and 3.95 ± 1.33 kg. Meanwhile, the amount of biochar product at 10 h and 15 h combustion modes are lower than at 6 h mode, and the amount of ash and incomplete biochar are higher.

Those results show that amount of biochar conversion by combusting in a long time is less effective than the average (about 6 h). Temperature is a key factor which significantly influences biochar production (Ondřej et al., 2013).The final product is shown in Figure 4.

Table 6. Biochar production in different conditions

Combustion mode	Weight of rice straw sticks (kg)	Weight of biochar (kg)	Amount of ash (kg)	Incompleted biochar (kg)
6 h	100	48.25 ± 2.25	0.75 ± 0.13	3.95 ± 1.33
10 h	100	47.05 ± 1.46	0.93 ± 0.17	4.55 ± 1.12
15 h	100	45.05 ± 2.18	1.08 ± 0.15	5.25 ± 0.71

Figure 4. Biochar products

The optimal condition for biochar production is combusting rice straw sticks in 6 h. This is the mode at which combustion time is shortest, amount of biochar is highest and amount of incomplete biochar is lowest (Figure 5). Similar to the study of Jindo et al. (2014), results illustrated biochar production obtained a high values at 10 h. Thereby showing the advantage of the experimental model of producing biochar at household scale is in line with the actual conditions of locality because of making use of the rich biomass sources. It is simple and easy to operate and has relatively short combusting time. Moreover, biochar contains a high organic concentration, so they can be used for soil emendation as well as enhancing agricultural plant productivity (Masulili et al., 2012; Jindo et al., 2014).

3.2.2. Construction and operation cost

- Construction cost

The construction cost is shown in Table 7. The burner is built mostly by bricks. The cost for materials is about 12.3 USD (0.06 USD/brick *200 bricks). The labor cost is about 10 USD (1 person/day). The burner can be used for 10 years. Hence, the construction cost per unit of product is not significant.

Table 7. Construction cost

Construction cost	Unit	Amount	Price	Total (USD)
Materials	Brick	200	0.06 USD/brick	12.3
Labor cost	Person	1	10 USD/day	10

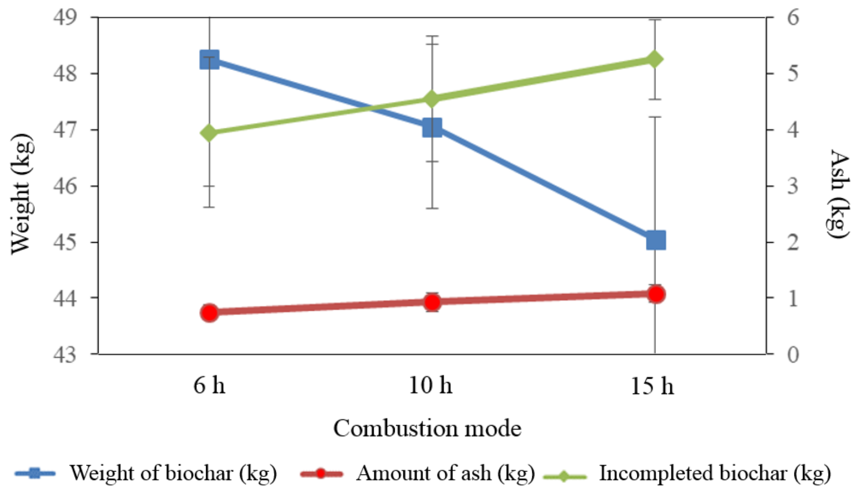

Figure 5. Comparison of biochar production in different conditions

- Material preparation

The cost for each kilogram of rice husk sticks is 0.03 USD (about 640 VND), including: 250 VND/kg rice husk, machine rent: 100 VND/kg, 150 VND/kg for transportation, labor 100 VND/kg, wastage of input 40 VND/kg (rate of wastage is 15%, get 85 kg rice husk stick for each 100 kg of rice husk) (Table 8).

The cost for each kilogram of rice straw sticks is 0.04 USD (970 VND), including: 100 VND/kg rice straws, machine rent: 250 VND/kg, labor 450 VND/kg, wastage of input: 20 VND/kg (get 85 kg rice husk straw for each 100 kg of rice straw) and 150 VND/kg for transportation.

Table 8. Cost of material preparation

Material preparation	Rice husk sticks (VND)	Rice straw sticks (VND)
Rice husk	250	100
Machine rent	100	250
Transportation	150	150
Labor	100	450
Wastage of input	40	20
Total	640 (0.03 USD)	970 (0.04 USD)

- Operation cost

The production is simple and easy to perform. It requires labor mostly at the beginning and at the end of the production. While the burner is active, the farmers can do another work while spending attention for burner. Thus, the operation cost is not significant.

3.2.3 Biochar quality

To evaluate the quality of biochar, some basic parameters are tested, such as humidity, amount of ash, sulfur, organic matter and thermal energy. According to Nguyen and Lehmann (2009), the organic materialisan important indicator related to biochar characteristics and quality. The results are presented in Table 9.

The study of Harvey et al. (2012) showed that by increasing temperature, hydrogen and oxygen levels were lost more than the carbon source. Temperature is an important factor, it affects the change of carbon level, hydrogen and oxygen concentration, and biochar characteristics (Bergeron et al., 2013).The results show that biochar produced in 6 h combustion mode has 35.3% organic matters and 4,895 kcal/kg in energy. Those produced in 10 h and 15 h have 33.5% and 29% organic matter, and 4,945 kcal/kg and 4,750 kcal/kg, respectively. Biochar has higher thermal energy than other materials such as chaff (3,500-4,200 kcal/kg), sawdust (4,385-4,700 kcal/kg), coal-dust (4,000-5,000 kcal/kg) and compressed rice straw (4,030 kcal/kg).

Table 9. Components of biochar

Sample	Humidity (%)	Ash (%)	S (mg/kg)	Organic matters (%)	Thermal energy (kcal/kg)
Rice straw	6.67	12.50	139.45	44.1	4,030
Biochar produced in 6 h	3.71	25.35	49.63	35.3	4,895
Biochar produced in 10 h	3.86	27.74	32.71	33.5	4,945
Biochar produced in 15 h	3.76	27.84	29.43	29.0	4,750

3.3.4. Economic benefits

With the approximate price of each kg of rice straw sticks and rice husk sticks is 1,200 VND (0.05 USD). The profits that farmers can gain for each kg of rice straw sticks and rice husk sticks are 230 VND (0.01 USD) and 560 VND (0.03 USD), respectively.

As compared to other commercial coal, the cost of biochar is much cheaper. The local households usually tend to use these products due to its affordable cost (Vongsaysana and Achara, 2009).While the price of coal is about 0.36 USD/kg (8,000 VND/kg), the cost of biochar is about 0.05 USD (1,000 VND/kg). In addition, the thermal energy of biochar is higher than other similar materials. Hence, it is one way of using biomass in a sustainable way while creating economic utility for households. It is suitable to apply this model to rural areas where the rate of using fuel is high (Suzette et al., 2011; Wrobel-Tobiszewska et al., 2015). In the context of fuel shrinking and the increasing price of other thermal energy, biochar becomes an alternative energy for rural areas. Especially under the context of climate change, the residue biomass is a serious air pollution source if they are burned as is currently done. Biochar has the ability to aid in coping with the production of greenhouse gases and climate change (Woolf et al., 2010; Vaccari et al., 2011).Therefore, this is a good solution to cut off emission and its impacts on environmental quality (Le et al., 2013).Another economic benefit from biochar production is saving the cost of fertilizer as well as enhancing soil quality (Tingting et al., 2013; Ahmed et al., 2016). Biochar can be used directly as a fertilizer or mixed with other commercial fertilizers. The high carbon concentration in biochar adds carbon for soil. However, in this study, we do not estimate this monetary benefit due to time limitation.

4. CONCLUSIONS

Emission from open buring rice straw is estimated. The green house gas emission from burning rice straw is high (concentrations of CO_2 and CO account for more than 95% of total emission). It is harmful for the environment and human health.The potential of producing biochar from rice straw in Go Cong Tay district is high. Because of the large area of rice field as well as the high productivity, rice straw is a cheap and available material. The experimental burner is simple and inexpensive. The operation is easy to perform. Hence, it is compatible with farmers and applicable for rural areas. The experiment shows that the most compatible mode for biochar production is combusting 100 kg of annular rice straw sticks in 6 h (the area of ventilation is 4 cm^2). The amount of completed biochar is highest, the amount of ash and the incomplete biochar are low.

The economic benefits from biochar is estimated. Biochar can be alternative energy for cooking at household scale due to its higher thermal energy compare to other types of energy and low cost.In this study, we have not considered the air emission from biochar production due to time and finacial constraints. It will be conducted in another phase of the study.The biochar can be used direcly as fertilizer to enrich the soil quality. It not only avoids the environment impacts from buring rice straw randomly but also save the cost for fertilizer. However, this study does not estimate the economic value of biochar as fertilizer due to time limitation.

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CONFLICT OF INTEREST

All authors have no conflict of interest to report.

REFERENCES

Ahmed A, Jiby K, Vijaya R. Biochar influences on agricultural soils, crop production, and the environment: a review. Environmental Reviews 2016;24(4):495-502.

Bergeron SP, Bradley RL, Munson A, Parsons W. Physico-chemical and functional characteristics of soil charcoal produced at five different temperatures. Soil Biology and Biochemistry 2013;58:140-6.

Cochran WG. Sampling techniques. 3rdEd. New York: John Wiley & Sons; 1977.

Danutawat T, Oanh TKN. Effects from open rice straw burning emission on air quality in the Bangkok Metropolitan Region. Science Asia 2007;33:339-45.

Duong TP, Yoshiro H. Current Situation and Possibilities of Rice Straw Management in Vietnam, 2015 [Internet]. 2017 [cited 2017 Dec 26]. Available from: http://www.jsrsai.jp/Annual_Meeting/PROG_52/ResumeC/C02-4.pdf

Food and Agriculture Organization of United Nations (FAO). Rice Market Monitor, 2016 [Internet]. 2017 [cited 2017 Dec 21]. Available from: http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Rice/Images/RMM/RMM-Jul17.pdf

Gadde B, Bonnet S, Menke C, Garivait S. Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. Environment Pollution 2009a;157:1554-8.

Gadde B, Menke C, Wassmann R. Rice straw as a renewable energy source in India, Thailand and the Philippines: overall potential and limitations for energy contribution and greenhouse gas mitigation. Biomass and Bioenergy 2009b;33:1532-46.

Harvey OM, Herbert BE, Kuo LJ, Louchouarn P. Generalized two-dimensional perturbation correlation Infrared spectroscopy reveals mechanisms for the development of surface charge and recalcitrance in plant-derived biochars. Environmental Science and Technology 2012;46:10641-50.

Hoang VD, Canh TN, Bien VN, Linh THN. Impacts of biochar and foliar fertilizer on growth and yield of tomato planted on sandy soil. Journal of Science and Development 2013;11(5):603-13.

Jindo K, Mizumoto H, Sawada Y, Sanchez-Monedero MA, Sonoki T. Physical and chemical characterization of biochars derived from different agricultural residues. Biogeosciences 2014;11:6613-21.

Jin SC, Sung HP, Sang CJ, Changkook R, Jong KJ, Min CS, Young KP. Production and utilization of biochar: a review. Journal of Industrial and Engineering Chemistry 2016;40:1-15.

Le HA, Hanh NTT, Linh LT. Estimated gas emission from burning rice straw in open fields in Thai Binh Province. VNU Journal of Science, Earth and Environmental Sciences 2013;29(2):26-33.

Mahdi SK, Qian Z, Dunli L, Yuan Z, Hua F, Yunlong Y. Biochar: a review of its impact on pesticide behavior in soil environments and its potential applications. Journal of Environmental Sciences 2016;44:269-79.

Masulili A, Utomo WH, Syechfani MS. Rice husk biochar for rice based cropping system in acid soil: the characteristics of rice husk biochar and its influence on the properties of acid sulfate soils and rice growth in West Kalimantan, Indonesia. Journal of Agricultural Science 2010;2(1):39-47.

Mendoza TC, Samson R. Strategies to avoid crop residue burning in the Philippine context. Proceedings of the International Conference on Frostbites and Sun Burns; 1999 April 24; San Salvador, QC: Canada; 1999. p. 2011.

Mubyana VC, Yeboah SO, Ringrose S. Fire and its influence on microbial community structure and soil biochemical properties in the Okavango Delta, Botswana. Scientific Research and Essay 2007;2(2):47-54.

Nam TS, Nhu NTH, Chiem NH, Ngan NVC, Viet LH, Kjeld I. To quantify the seasonal rice straw and its use in different provinces in the Vietnamese Mekong Delta. Scientific Journal of Can Tho University 2014;32:87-93.

Nguyen BT, Lehmann J. Black carbon decomposition under varying water regimes. Organic Geochemistry 2009;40:846-53.

Nipa T, Patma V, Phrueksa L, Patcharee S. Biochar and rice straw have different effects on soil productivity, greenhouse gas emission and carbon sequestration in Northeast Thailand paddy soil. Agriculture and Natural Resources 2016;50(3):192-8.

Norusis M. The SPSS 13.0 Guide to Data Analysis. New Jersey, USA: Prentice Hall; 2005.

Ondřej M, Peter B, Andrew C, Saran S. Influence of production conditions on the yield and environmental stability of biochar. Fuel 2013;103:151-5.

Rosmiza MZ, Amriah B, RosnizaAznie CR. Impact of rice straw development towards agricultural environment and farmers's socio-economy in MADA Region, Kedah. International Proceedings of Economics Development and Research 2012;54:245-9.

Ruilun Z, Zheng C, Chao C, Xiaohui W, Yizong H, Bo X, Guoxin S. Effect of biochars from rice husk, bran, and straw on heavy metal uptake by pot-grown wheat seedling in a historically contaminated soil. BioResources 2013;8(4):5965-82.

Shijian Y, Hongping H, Shangling L, Dong Cn, Jianxi Z. Quantification of crop residue burning in the field and its influence on ambient air quality in Suqian, China. Atmospheric Environment 2008;42(9):1961-9.

Suzette PG, Jonathan KY, David G. The economic value of biochar in crop production and carbon sequestration. Energy Policy 2011;39(10):6344-50**.**

Tien Giang Department of Agriculture and Rural Development (TGDOARD). The 2014 Statistical Reports of Agriculture and Rural Development in Tien Giang Province, Tien Giang; 2015.

Tien Giang Statistics Office (TGSO). Tien Giang Statistical Year Book 2016. Hanoi: Statistical Publishing House; 2017.

Tingting Q, Xuesong Z, Jianyang H, Hong J. Effects of environmental conditions on the release of phosphorus from biochar. Chemosphere 2013;93(9):2069-75.

Thongchai K, Oanh TKN. Development of spatial and temporal emission inventory for crop residue field burning. Environment Model Assessment 2011;16: 453-64.

Tung SN, Cu XN, Hai XN. Impact of Rice straw burning methods on soil temperature and microorganism distribution in the paddy soil ecosystems. Journal of Agricultural and Biological Science 2004;9(5):157-60.

Vaccari F, Baronti S, Lugato E, Genesio L, Castaldi S, Fornasier F, Miglietta F. Biochar as a strategy to sequester carbon and increase yield in durum wheat. European Journal of Agronomy 2011;34:231-8.

Vongsaysana S, Achara U. Comparison of the physical and chemical properties of briquette and wood charcoal in Khammouane province, Lao PDR. Environment and Natural Resources Journal 2009;7(1):12-24.

Woolf D, Amonette JE, Street-Perrott FA, Lehmann J. Sustainable biochar to mitigate global climate change. Nature 2010;1:1-9.

Wrobel-Tobiszewska A, Boersma M, Sargison J, Adams P, Jarick S. An economic analysis of biochar production using residues from Eucalypt plantations. Biomass and Bioenergy 2015;81:177-82.

Yamane T. Statistics, an Introductory Analysis. New York: Harper and Row; 1967.

Zha S, Zhang S, Cheng T, Chen J, Huang G, Li X, Wang Q. Agricultural fires and their potential impacts on regional air quality over China. Aerosol and Air Quality Research 2013;3:992-1001.