Characterization of Rice Husk Biochar and Its Particle Size Effects on Soil Properties in Sandy Loam Soil

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ABSTRACT

This study aimed (i) to characterize biochar derived from rice husk using a traditional kiln method, and (ii) to evaluate leaching reduction potential by differentiating sizes of rice husk biochar (RHB). For this study, RHB was produced at 300 to 550 °C using the traditional kiln method and was conducted at Naresuan University, Thailand. Morphology of RHB was classified using Field Emission Scanning Electron Microscope together with Energy Dispersive X-ray Spectrometer (FESEM-EDS). Three different sizes of RHB: (i) less than 0.25 mm, (ii) 0.25 – 1 mm, and (iii) 1 – 2 mm were used at the rate of 2% w/w to mix with the sandy loam soil and tested in soil column. The results showed that the traditional kiln method could produce RHB of about 40% of the total fresh weight. The average pore size was 10.64 µm. Carbon was a highest element content in RHB (> 60%), then oxygen (~20%) and silica (~15%), respectively. Observed pore sizes were similar for all three RHB samples. After soil incubation, a smallest biochar size (<0.25 mm) was 17% greater potential in leaching reduction as compared to control. Besides, medium (0.25 – 1 mm) and large (1 – 2 mm) sizes of RHB reduced leaching by 13%, and 10%, respectively. Application of RHB decreased bulk density and increased soil nitrogen adsorption capacity.

1. INTRODUCTION

Soil is the most fundamental resource and stores essential nutrients and microflora for agricultural production systems [1]. Soils with low fertility can hinder sustainable agricultural practices because intensive farming has currently caused soil degradation problems. Moreover, current issues of rapid depletion of agricultural areas, food self-sufficiency and security, environment, climate change, waste management, and soil degradation have warranted the need for the identification of efficient sustainable strategies to alleviate these issues. One of the sustainable options and solutions could be the utilization of biochar in the soil [2]. Biochar is a stable form of carbon that is produced through the pyrolysis process of feedstock biomass in a restricted air condition at temperatures between 300 to 700ºC [3]. Its application has been issued as a practicable strategy to improve soil health, increase crop productivity, conserve water and reduce irrigation and fertilizer requirements, sequester carbon, and a promising method for sustainable management of agricultural waste and biomass [4], [5], [6].

Rice is a staple food for many people, with more than 500 million tons produced annually. Rice husk, on the other hand, which is a by-product of rice processing, is annually produced approximately 140 million tons and it causes a significant waste disposal problem [7]. Therefore, agricultural wastes can convert into biochar via the traditional biochar kiln. Therefore, they have a lot of advantages including producing energy, soil carbon sequestration, improvement of soil fertility, and encouraging plant growth [8], [9]. Rice husk biochar has the potential as a soil amendment because it consists of high percentages of plant nutrients, especially potassium and silicon [10]. Furthermore, using biochar has been confirmed in reducing nutrient leaching when incorporating biochar into the soil [4], [11], [12]. In addition, biochar has a positive influence on soil structure. It significantly decreased soil bulk density [13], increased soil cation exchange capacity [14],

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neutralized soil acidity and improved soil nutrient availability [12], [15], increased overall net soil surface area, and improved soil water retention capacity [16], [17]. This is because biochar's porous structure works as a sponge, retaining water and nutrients and acting as a habitat for beneficial soil organisms, improving their activity, resulting in increased soil aggregate stability and porosity [18]. In previous studies, applying biochar as a soil amendment could enhance the productivity of crops and the quality of degraded soils. In addition, the particle size of biochar influenced the interaction between soil and biochar [19]. For example, de Jesus Duarte et al. (2019) [20] investigated the effect of biochar particle size on the soil's quality attributes. The results established that the 0.15 mm of biochar particle size resulted in an increase in water retention in loamy and sandy soils, but mainly in the loamy soil. Soil bulk density reduced marginally, particularly in loamy soils with biochar of more than 2 mm and in sandy soils with a size of 0.15–2 mm biochar.

Rice husk conversion to biochar is an excellent agricultural management strategy, and its favorable effect on soil is well-documented. It is therefore a promising method for improving the physical, chemical, and biological soil properties and proper agricultural waste and biomass management [21]. However, the efficiency of biochar application as a soil amendment depends on many factors including feedstock type and the size of biochar particles. The effect of the biochar particles on the soil matrix is highly dependent on the biochar particle sizes [22], [23]. Research has shown that incorporating biochar into the soil can substantially increase crop production. However, a study on the biochar particle sizes on soil properties is still lacking. Therefore, it is crucial to understand the effects of different particle sizes of biochar on some chemical and physical soil properties. The objectives of this study were to characterize biochar derived from rice husk using a traditional kiln method, and (ii) to evaluate leaching reduction potential by differentiating sizes of rice husk biochar (RHB) particles.

2. MATERIALS AND METHODS

2.1 Rice husk biochar production

A Biochar kiln of 50 cm in height with 56 cm diameter was built from a metal sheet (Fig. 1). The traditional kiln was composed of i) an inner chamber, ii) an outer chamber, and iii) a cover. The inner chamber was made with a diameter of 20 cm for producing heat to pyrolysis the biomass placed in the outer chamber. The inner chamber was created with a 10 mm of thicker metal sheet which was permanently fixed. The inner chamber was filled with fuel materials that were used for lightning purposes. The top of the outer chamber can be sealed by a cover plate and the chimney can be inserted. The rice husk was inserted in the space between the chamber and the outer chamber. The heat was generated in the inner chamber and the lid was tightly closed. The rice husk material was burnt hotter for around 30 to 40 min in the outer chamber and began to burn after 60 min. It released gases and the flame turned blue without smoke. It showed that the process was a completely burning fuel. Simultaneously, thermocouple probes were set up inside the kiln in radial and longitudinal positions. The temperature recorded ranges from 250 to 550 ℃ (Fig. 2). The RHB was produced by burning firewood at the bottom of the biochar kiln to trigger the pyrolysis process for 4 hours. The RHB was ground and sieved into three different sizes; less than 0.25 mm (small), 0.25 – 1 mm (medium), and 1 – 2 mm (large).

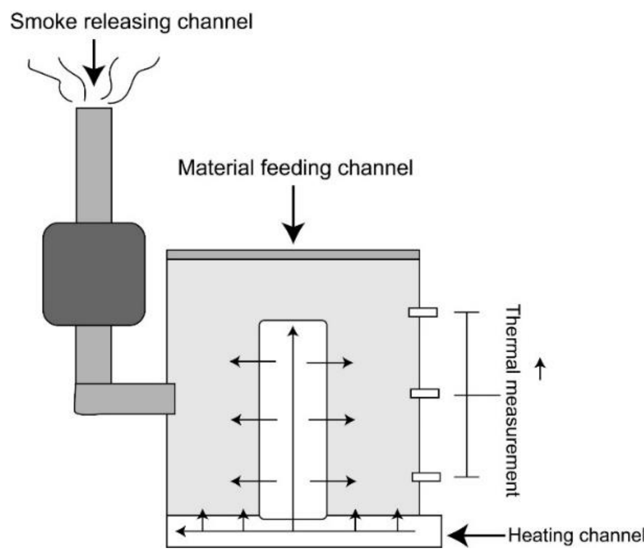

Fig. 1 Traditional biochar kiln.

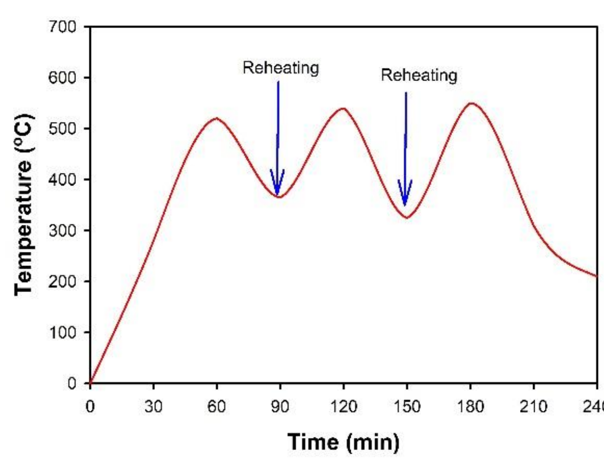

Fig. 2 Pyrolysis temperature of RHB production in biochar kiln.

2.2 Characterization and morphology of rice husk biochar

In order to analyses the structure of the biochar particles, a small quantity of samples was positioned in sample holder using a cupper conductive tape. After that, samples were characterized by using a High-Resolution FE-SEM (Thermo Scientific Apreo S, USA). The microscope was connected with an Energy Dispersive X-Ray detector that was utilized to assess the elemental composition of rice husk biochar.

2.3 Soil and biochar analysis

In the experiment, sandy loam soil samples were collected from the topsoil at 0-20 cm depth from Wang-Thong district, Phitsanulok province, Thailand. The soil is classified as a loamy-skeletal, siliceous, isohyperthermic kanhaplic [24]. The initial soil and rice husk biochar properties are presented in Table 1.

For soil preparation, soil samples were air-dried, and ground to pass through a 2-mm sieve. The physical and chemical properties of soil and biochar were analyzed as follows: electrical conductivity (EC) by EC meter, the ratio of soil per water as 1:5 [25] soil pH by pH meter (1:1 of Soil:H_2O) [26]. The soil texture was determined by the hydrometer method [27]. Bulk density (BD) was analyzed by the soil core method [28], and Total nitrogen (N_{tot}) was determined by the Kjeldahl method [29] The available phosphorous (P_{ava}) was assessed using the Bray II extraction method. The exchangeable potassium (K) was extracted with ammonium acetate (NH_4OAc) and then measured by atomic absorption spectrophotometry.

Table 1 Soil and biochar properties

Sample	Chemical properties					Texture (%)		
	pH	EC (µS/cm)	N (%)	P (mg/kg)	K (mg/kg)	Sand	Silt	Clay
Soil	5.7	29.2	0.14	8.49	99.0	71.7	23.7	4.6
Biochar	7.7	113.2	0.75	73.13	536.6	-		

2.4 Experimental design

A greenhouse experiment was arranged at Naresuan University, Thailand. The experiment was laid out as a 4 × 2 factorial in a completely randomized block design (CRD) plus 1 control with 3 replicates. The first factor was three biochar particle sizes (no biochar, < 0.25 mm, 0.25 - 1 mm, and 1 - 2 mm), and the second factor was the addition of chemical fertilizer (0.75 N, 0.75 P, and 0.75 K and no addition of chemical fertilizer). The application rate of biochar applied at 2% w/w with 4 kg of sandy loam soil in each soil column.

2.5 Soil column and leachate collection

Soil plastic columns of 20 cm in height and an external diameter of 17 cm were constructed. At the bottom of each column, a drain hole (3 mm) was attached tube for collecting water draining out the bottom of the columns. A small amount of coarse sand (5 mm) was filled at the bottom of each column. The mixture of soil and biochar was packed in PVC columns according to each treatment. The leaching soil columns were irrigated with tap water. Moreover, the soil moisture was kept at 80% of WHC (Fig.3). All soil columns were regularly weighed for three times a week to compensate any water loss through evaporation. The leaching rate of each treatment was collected after 5 times of irrigation. After soil incubation, the soil parameters including pH, EC, nutrient availability (N_{tot}, P_{ava}, and K_{exc} and bulk density and WHC) were analyzed.

2.6 Statistical Analysis

Collected data including soil parameters, nutrients and water leached were statistically analyzed using Analysis of Variance (ANOVA). Least Significant Difference (LSD) was performed for significant differences among treatments at $P<0.05$ using Statistix 10 software.

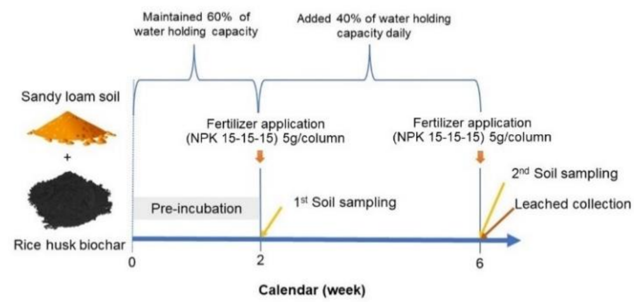

Fig. 3. Soil incubation management and sampling calendar.

3. RESULTS AND DISCUSSION

RHB used in this study was produced by traditional kiln method. The results indicated that the traditional kiln method was capable of producing RHB of about 40% of the total fresh weight. Generally, biochar produced in a muffle furnace had about 60 – 70 % of weight loss (data not shown). The weight loss of these two methods is more likely similar. However, traditional kiln method can produce RHB in much more quantity as compared to a muffle furnace. There is a certain difference of these two methods, it is a burning temperature. A muffle furnace is able to keep the temperature constant, however, traditional kiln method cannot keep constant temperature throughout a pyrolysis process. Therefore, character and morphology of RHB produced by traditional kiln method is examined and results are presented below.

3.1 Morphology of rice husk biochar produced by a traditional kiln method

Morphology of RHB is shown in Fig. 4. Low magnification images (100x) showed a similar structure of smooth lateral surfaces and long channels of RHB. At high magnification (1000x), the pores and channel formations in biochar were clearly displayed. FESEM had an organized honeycomb structure of RHB with plentiful pores hidden under the biochar surface, which provided them with a high specific surface area. Pores size and distribution did not vary between different biochar particle sizes. The average pore size was 10.64 µm. Nardon C. and Samsuri A. W. [4] presented that RHB produced by pyrolysis process at temperature of about 500 ºC had a pore like honeycomb which is similar to this study. Even though this traditional kiln mehod cannot keep the temperature constant at 500 ºC, however, it is able to produce RHB with large amount of pores and large quantity of biochar.

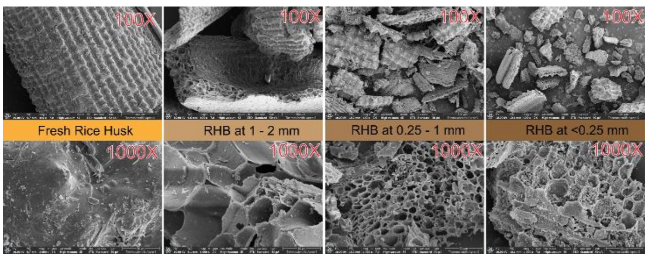

Fig. 4. Morphology of rice husk and rice husk biochar (RBH) at different sizes at two magnifications; 100x (top) and 1000x (bottom) by FESEM-Eds.

For EDS analysis of RHB, the result is presented in the mass percentage of the samples (Fig. 5). EDs of RHB indicates that C (> 60%) and O (~20%) silica (~15%) where the major elements including some amount of mineral such as P, K, Mg, Ca, Fe. These results revealed that carbon was the main skeleton with oxygen and silica in the RHB.

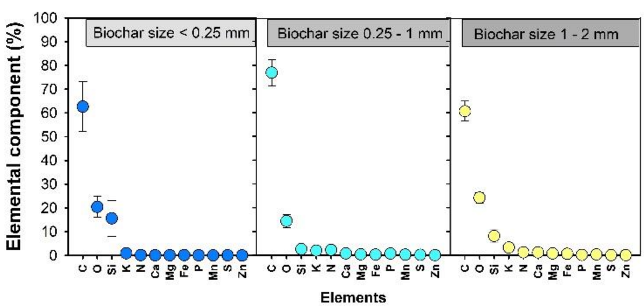

Fig. 5 Element composition through EDs analysis

3.2 Effect of rice husk biochar on some soil properties

The fertilizer application has a statistically significant impact on soil pH and EC. However, three different RHB particle sizes did not have a significant effect on soil pH and EC. Moreover, the pH, EC, and BD were not affected by the interaction between biochar particle sizes and fertilizer application (Table 2). BD was affected by biochar particle size at pre-incubation and the end of the experiment. The BD of soil (control) after a week of pre-incubation was 1.70 g/cm^3. It increased to 1.72 g/cm^3 at the end of the study period. The increase of BD is due to the result of wetting and drying cycles resulting in compaction and rearrangement of soil particles. BD is an indicator of soil compaction. The reduction in the BD is crucial because it contributes directly to water infiltration, soil aggregation, root and plant development, and production [20]. The application of RHB could reduce the BD of the soil. For the treatment of RHB and soil mixture, bulk density ranged from 1.60 g/cm^3 to 1.65 g/cm^3. More profoundly, the reduction in the BD of the soil was greater with the larger biochar particle size in sandy loam soil of 1.60 g/cm^3 compared to the control of 1.72 g/cm^3 at the end of the experiment. The large and medium size of biochar decreased the BD by 5% and 6%, respectively. In contrary, small particle size of biochar did not show much difference in decreasing the BD in sandy loam soil. This indicates that large particle size of biochar decreased BD than the small size of biochar. The results of this study were shown and proved that application of RHB influenced the soil bulk density and soil chemical and physical properties. In this study, we only used 2% of RHB to mix with the sandy loam soil, however, the effect of biochar on soil properties is clearly presented. Likewise, other studies found that the application of rice husk biochar at a rate of 2 % (w/w) to sandy loam soil significantly reduced soil bulk density [30]. Toková, L., et al., [31] study on biochar applied at 20 t/ha and they presented a significant reduced in soil bulk density by 12%. Sizes of RHB had also a significant effects on soil property.

Table 2. Effect of RHB particle sizes on soil properties

Factors	**After pre-incubation**			**End of experiment**		
	pH	EC (µS/cm)	BD (g/cm^3)	pH	EC (µS/cm)	BD (g/cm^3)
Particle sizes						
Soil (control)	5.7	374.93	1.70a	5.5b	236.58	1.72a
Soil + biochar (< 0.25mm)	5.9	283.39	1.64ab	6.0a	230.70	1.65b
Soil + biochar (0.25-1mm)	5.8	366.79	1.62b	6.0a	272.12	1.61bc
Soil + biochar (1- 2 mm)	5.8	317.55	1.60b	6.1a	235.20	1.60c
Fertilizer						
-F	6.23a	53.29b	1.62	6.3a	125.09b	1.64
+F	5.45b	618.03a	1.65	5.5b	362.21a	1.66
F- test						
Particle size (P)	ns	ns	*	**	ns	**
Fertilizer (F)	***	***	ns	***	***	ns
P * F	ns	ns	ns	ns	ns	ns
CV (%)	4.49	28.06	3.12	4.06	34.33	1.86

Note: a, b represent significant difference among treatments at

$p<0.05$ according to the LSD test. Levels of significance *p < 0.05, **p < 0.01, ***p < 0.001, ns = non-significant, SB= Small biochar size. MB= Medium biochar size, LB= large biochar size.

The results obtained from this study indicated that large particle size of RHB decreased BD more than the small size of RHB. The RHB particle size can be associated with an arrangement of the particles of biochar in the volume of the soil, where the smallest particles can fill up the pores in the soil, this is not possible if the biochar particle is large-sized. In this arrangement, more biochar is located inside the pores of the soil, contributing to a reduction of the total porosity and an increase in the soil bulk density. Likewise, the soil pH and EC value slightly increased regardless of different particle sizes of biochar application as shown in Table 2. Addition of RHB to soil showed an increase in pH value from 5.7 to 6.5 at the end of the experiment. Regarding EC, the value increased to 52.81µS/cm, 73.94 µS/cm and 63.5 µS/cm for small, medium and large particle size of biochar, respectively, which is contrary to the control soil of 45.54 µS/cm. Carter et al. [32] conducted the pot culture experiment in sandy loam soil to investigate the impact of biochar application on soil properties and crop growth of lettuce and cabbage. The study shows an increase in pH from 5.5 to 6.1 when applied biochar into the soils.

3.3 Effect of particle size of RHB on water leaching

In the treatment of RHB, cumulative irrigation water leaching into the soil was minimized. The soil with the smallest RHB particle size treatment was reduced by around 17% cumulative water leaching, as compared to the control (Table 3). The reduction in water leaching reached 13% and 10 % for the soil mixed with the RHB particle size of 0.25 – 1 mm and 1 – 2 mm, respectively. The smallest particle size of the RHB makes for the fine biochar particles to reside in the pore spaces between soil particles, therefore, limiting water pathways and reducing the infiltration of water in the soil [33]. Similarly, de Jesus Duarte et al. [20] studied the effect of biochar particle size on the quality characteristics of the soil. The results demonstrated that the particle size of biochar is crucial for water retention, water availability, and pore size distribution. It was reported that biochar had a great potential to increase soil water retention. The smaller particle size of <0.15 mm improved water retention in the loamy soil. This increase could be associated with a intraparticle porosity, a high specific surface area that increased with the decrease of particle size. These particles could contribute to the creation of pores between biochar particles and soil particles (inter-pores) which contributed to decrease the cumulative infiltration in soil [34]. This study proved that RHB could contribute to reducing the water and nutrient leaching, increase the water holding capacity in soils, which would be beneficial for plant root elongation and available water.

3.4 Effects of rice husk biochar particle sizes on soil nutrients adsorption

Fertilizer was applied at four weeks after pre-incubation ended (for a total of six weeks from the start) to assess nutrient adsorption capacity (Table 4). N_{tot} at 4 weeks after pre-incubation ended revealed a significant effect of RHB particle sizes and fertilizer application on N_{tot} absorption. The mixture of soil and RHB at <0.25 mm and 1 – 2 mm adsorbed higher N_{tot} than soil alone and the mixture of soil and RHB at 0.25 – 1 mm, significantly. For P_{ava} and K_{exc}, there were no significant differences among treatments. Sizes of RHB had no significant effect on P_{ava} and K_{exc} adsorption in soil. Moreover, N_{tot}, P_{ava} and K_{exc} were not affected by biochar particle size × fertilizer application interaction In sandy loam soil, it is basically low in nutrient adsorption capacity, however, according to Kuo et al. [11] , and Zhou (2019) [35] biochar promotes soil health by enhancing the sandy loam soil's capacity to hold nutrients and reducing nutrient leaching. Our study showed similar results that biochar improved N_{tot} adsorption capacity, but had no effect on K_{exc} adsorption capacity. Low cation exchange capacity is dominant in sandy soil. The mixture of biochar and sandy soil may need more incubation time to improve its aggregate to be more suitably for K_{exc} adsorption.

Table 3. Effect of different sizes of rice husk biochar and fertilizer on water leachate

Factors	Water leachate (%)			
	0 DAT	**8 DAT**	**18 DAT**	**End of experiment**
Particle sizes	69.80a	65.64a	62.02a	58.00a
Soil (control)	55.10c	51.54b	47.57c	44.31d
Soil + SB (<0.25mm)	57.02b	51.00b	53.57b	51.88c
Soil + MB (0.25-1mm)	58.04b	55.54b	55.97b	55.33b
Soil + LB (1-2mm)	69.80a	65.64a	62.02a	58.00a
Fertilizer				
-F	60.02	55.61	55.43	52.58
+F	59.95	56.40	54.14	52.18
F- Test				
Particle size (P)	***	***	***	***
Fertilizer (F)	ns	ns	ns	ns
P * F	ns	ns	ns	ns
CV (%)	2.41	6.97	8.57	2.92

Note: a, b represent significant difference among treatments at $p<0.05$ according to the LSD test. Levels of significance **p < 0.01, ***p < 0.001, ns = non-significant, SB= Small biochar size. MB= Medium biochar size, LB= large biochar size.

Table 4. Macro nutrients adsorption in soil at 4 weeks of soil pre-incubation

Factors	Nutrients		
	N_{tot} (%)	P_{ava} (mg/kg)	K_{exc} (mg/kg)
Particle sizes			
Soil (control)	0.0623b	40.55	364.72
Soil + SB (<0.25mm)	0.0692a	41.04	357.72
Soil + MB (0.25-1mm)	0.0693a	41.00	387.11
Soil + LB (1-2mm)	0.0630b	41.00	372.19
Fertilizer			
-F	0.057b	35.50b	143.25b
+F	0.075a	46.24a	597.46a
F- Test			
Particle size (P)	***	ns	ns
Fertilizer (F)	**	***	***
P * F	ns	ns	ns
CV (%)	4.9	4.7	28.9

Note: a, b represent significant difference among treatments at p<0.05 according to the LSD test. Levels of significance **p < 0.01, ***p < 0.001, ns = non-significant, SB= Small biochar size. MB= Medium biochar size, LB= large biochar size.

4. CONCLUSIONS

The pores distribution and sizes of RHB did not vary between different biochar particle sizes. The average pore size was 10.64 µm. RHB indicates that C, O, and Si were the major elements including some amount of minerals such as N, P, K, Mg, Ca, Fe. The soil properties, such as BD and pH, water holding capacity, were dependent on the biochar size in sandy loamy soil. The biochar has a great potential to decrease soil BD, improves soil water retention in the finest fraction of sandy loam soils. Different sizes of RHB have also the effect on nutrient adsorption capacity in soil. The mixture of soil and RHB at the size of < 0.25 mm and 1-2 mm demonstrated a significant higher N_{tot} than control. The benefits found in our research show that this material can be recommended for farmers as a soil amendment to improve the chemical, physical and hydrological quality of the soil.

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