Effects of Biochar on Soil Properties, Soil Carbon Sequestration and the Growth of Hom Hua Bon Rice

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Abstract:

This study aimed to investigate the effects of biochar derived from different types of agricultural biomass on soil properties, soil carbon sequestration, and the growth of Hom Hua Bon rice. The experiment consisted of five treatments: Treatment 1: control treatment (soil only); Treatment 2: soil mixed with biochar derived from para rubber wood sawdust; Treatment 3: soil mixed with biochar derived from corn leaves and stalks; Treatment 4: soil mixed with rice husk biochar; and Treatment 5: soil mixed with rice straw biochar, with biochar applied at a rate of 3% (w/w). The experiment was conducted using a completely randomized design, with three replicates per treatment. Soil properties, including pH, bulk density, water holding capacity, organic matter content, macronutrients (N, P, K), and soil carbon content, were measured before and after rice cultivation following GLOBE protocols. Rice growth parameters, including germination rate, soil moisture, and plant height, were recorded weekly over a four-week cultivation period. Data were analyzed using one-way analysis of variance (ANOVA).

The results indicated that all biochar treatments significantly improved soil physical properties compared with the control ($P < 0.05$). Biochar application reduced soil bulk density to 0.80–1.05 g/cm^3, while soil water holding capacity increased from 35.00 ± 3.00% in the control to 50.00–65.00% before planting. After planting, soil amended with para rubber wood sawdust biochar exhibited the highest water holding capacity (85.00 ± 6.00%). Soil carbon content increased significantly in all biochar-amended soils, with the para rubber wood sawdust biochar treatment showing the greatest increase, from 4.61 ± 0.07% before planting to 4.99 ± 0.10% after planting, whereas the control showed only a slight increase (from 0.92 ± 0.02% to 1.07 ± 0.03%). Significant differences in rice growth were observed among treatments ($P < 0.05$), with the para rubber wood sawdust biochar treatment achieving the highest germination rate (81.44 ± 0.50%) and the greatest plant height at week 4 (19.12 ± 1.19 cm), while the control exhibited the lowest germination rate (25.89 ± 0.50%) and plant height (13.56 ± 0.56 cm). These findings indicate that biochar, particularly that derived from para rubber wood sawdust, has strong potential for improving soil quality, enhancing soil carbon sequestration, and promoting sustainable cultivation of Hom Hua Bon rice.

Keywords: *Biochar / Hom Hua Bon Rice / Soil Quality / Carbon Sequestration*

Research Question:

1. Do different types of biochar have different effects on soil properties and soil carbon sequestration?
2. Do different types of biochar have different effects on the growth of Hom Hua Bon rice?

Hypothesis:

1. The different types of biochar have different effects on soil properties and soil carbon sequestration.
2. The different types of biochar have different effects on the growth of Hom Hua Bon rice.

Objective:

1. To study the effects of biochar on soil quality including soil texture and color, Loss on Ignition, bulk density, moisture content, water-holding capacity, pH, organic carbon and NPK.
2. To study the effects of biochar on the growth rate of Hom Hua Bon rice.

Introduction and Review of Literature

Southern Thailand is an area with diverse agricultural systems, where land is continuously utilized to establish food security for local communities. Upland rice is a significant food crop that farmers commonly plant in areas where rubber or oil palm trees have been recently felled, as well as an intercrop to maximize land-use efficiency. Hom Hua Bon rice is a traditional upland rice variety from Krabi Province. Its distinctive characteristics include red-coated grains, a fragrant aroma, soft texture, and high nutritional value, containing relatively high levels of gamma-oryzanol (γ-oryzanol) and total antioxidants.

However, the agricultural sector faces problems with soil degradation resulting from the burning of agricultural waste and the long-term use of chemical fertilizers. This has led to a decrease in soil fertility. Furthermore, the burning of residues is a major source of greenhouse gases. Thailand generates approximately 50–60 million tons of stubble and rice straw annually, which produces about 27 million tons of carbon dioxide per year. This practice also forces farmers to become more reliant on chemical fertilizers (Land Development Department and Ministry of Agriculture and Cooperatives, 2005).

A sustainable approach to managing agricultural waste is the production of biochar through the pyrolysis process under oxygen-limited conditions. This method can sequester carbon in the soil and help increase water holding capacity, as well as the cation exchange capacity (CEC) of the soil, which positively affects plant growth (Lehmann et al., 2006).

Therefore, the authors have developed this project entitled "Effects of Biochar on Soil Properties, Soil Carbon Sequestration, and the Growth of Hom Hua Bon Rice" to serve as a guideline for efficient and environmentally friendly agricultural waste management for long-term sustainability.

Research Method and Materials *(including GLOBE Data!)*:

Materials:

1) Rice husk
2) Planting soil
3) Hom Hua Bon rice seeds
4) Para rubber wood sawdust
5) Rice straw
6) Corn leaves and stalks

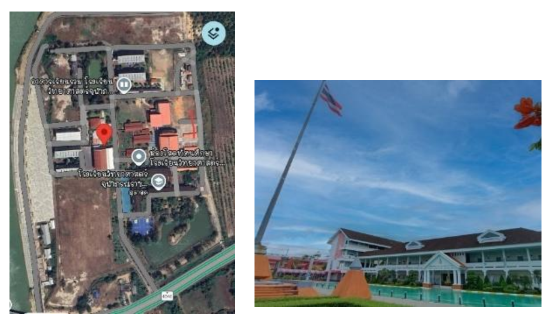
Equipment:

1) Planting pots
2) Soil color and texture test kit
3) NPK test kit
4) pH meter
5) Soil moisture meter
6) Soil water holding capacity test kit
7) Digital Scale
8) High-temperature Furnace

Study site

The study was conducted in two locations. The first site was a rice field located in Khok Saba Sub-district, Nayong District, Trang Province, at the coordinates 7°30′48.1"N, 99°44′19.4"E. The second site was Princess Chulabhorn Science High School, Trang, located in Bang Rak Sub-district, Mueang Trang District, Trang Province, at the coordinates 7°33′13.1"N, 99°33′26.8"E.

Picture 1: The rice field is located in Khok Saba Sub-district, Nayong District, Trang Province.



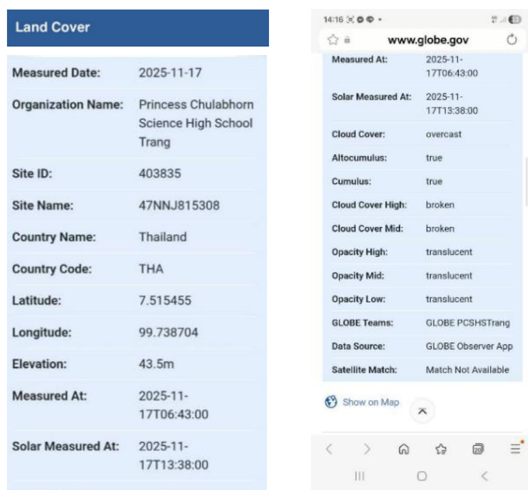
Picture 2: Princess Chulabhorn Science High School, Trang

Research Method

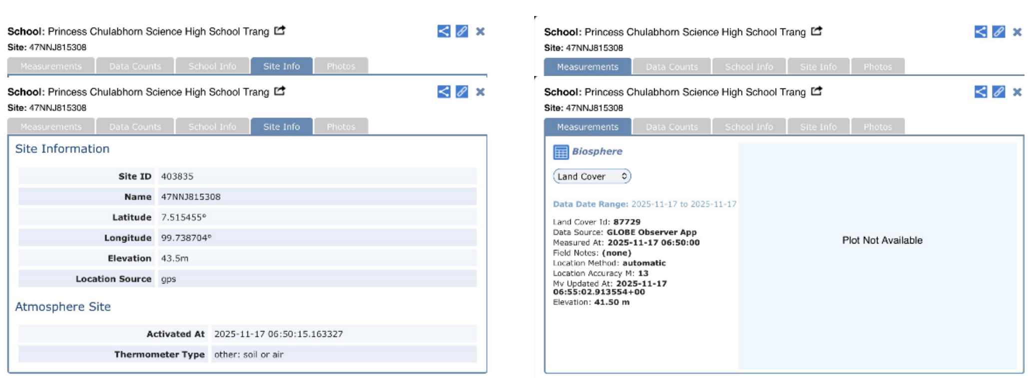
1) Data Collection of Soil Quality

Soil property data collection consisted of the following steps:

1) Sampling locations were identified, and soil samples were collected.
2) Land use information at each sampling site was recorded using the GLOBE Observer application. Physical soil properties were analyzed, including soil texture, soil moisture, bulk density, and water holding capacity. Chemical soil properties were analyzed, pH, NPK, Loss on Ignition, and soil carbon sequestration.
3) All measurements were repeated three times, and the mean ± SD was calculated.
4) Send the information to GLOBE Data Entry.



Picture 3: Land Cover Observation



Picture 4: GLOBE Data Entry

1.1 Soil Color: using the Munsell Soil Color Book.

1.2 Soil Texture: following the GLOBE protocol steps:

1.2.1 Soil samples were air-dried for 8 hours.

1.2.2 The dried soil was sieved through a mesh screen.

1.2.3. The soil was moistened, and soil texture was determined by comparing its characteristics with a field guide.

1.3 Bulk Density: Bulk density was calculated by weighing dry soil in a 100 cm^3 volume using the formula: Bulk density = dry soil mass / soil volume

1.4 Water Holding Capacity: Water holding capacity was determined by weighing dry and wet soil and calculated as: Water holding capacity (%) = (wet soil – dry soil) / dry soil × 100

1.5 Soil Moisture: using a soil moisture meter.

1.6 Soil pH: using a pH meter.

1.7 NPK: mixing 20 g of sieved dry soil with 80 mL of distilled water. The mixture was stirred and allowed to settle, then the clear soil solution was collected. A 2.5 mL soil extract was transferred into a test tube, and HI 3895-N, HI 3895-P, and HI 3895-K reagents were added to analyze nitrogen, phosphorus, and potassium, respectively. The results were determined by comparing the color of the solution with a color chart.

1.8 Loss on Ignition (%LOI): heating soil at 450°C for 5 hours and calculating using a formula: Loss on Ignition (%) = (weight before combustion – weight after combustion) / weight before combustion × 100

1.9 Soil organic carbon (%OC): soil organic matter (%LOI) using the following equations:

$\%OC = -0.21 + 0.40 (\%LOI)$ for $\%LOI < 0.20$

$\%OC = -0.33 + 0.43 (\%LOI)$ for $\%LOI > 0.20$

2) Biochar Production

2.1 Agricultural residues were air-dried prior to pyrolysis.

2.2 The dried agricultural materials were pyrolyzed in a furnace at a temperature of 450 °C for 3 hours.

3) Cultivation of Hom Hua Bon Rice

Number and details of experimental treatments:

Soil-to-biochar ratio was 100% soil: 3% biochar (w/w).

Treatment 1: Control treatment: soil only

Treatment 2: soil mixed with biochar derived from Para rubber wood sawdust

Treatment 3: soil mixed with biochar derived from corn leaves and stalks

Treatment 4: soil mixed with rice husk biochar

Treatment 5: soil mixed with rice straw biochar

3.1 Hom Hua Bon rice seeds were soaked overnight.

3.2 Seeds were sown into planting holes at a rate of three seeds per hole. Each pot contained three holes, with a total of 15 pots used in the experiment.

3.3 Plants were watered once daily for a period of 4 weeks.

4) Analyzed the growth of Hom Hua Bon rice

4.1 Rice growth was recorded weekly for 4 weeks, including the following parameters: Seed germination rate

4.2 Soil moisture was measured using a soil moisture meter for 4 weeks.

4.3 Plant height: growth was measured using a ruler from the base of the plant to the tip

Data analysis

1) Soil properties and soil carbon sequestration among the experimental treatments were compared.
2) The growth of Hom Hua Bon rice among the experimental treatments was compared using Anova one and two-way variance (one-two-way ANOVA).

Results

The results of soil quality and different types of biochar

The analysis results indicated that biochar derived from different types of biomass materials exhibited higher pH values than soil, falling within the alkaline range (8.00–9.00), whereas the soil showed a slightly acidic pH (6.00 ± 0.20). Biochar produced from Para rubber wood sawdust had the highest water holding capacity (85.00 ± 3.00%), while rice husk biochar exhibited the highest pH value (9.00 ± 0.20). Overall, biochar showed variations in the concentrations of major nutrients depending on the type of raw material used, as presented in **Table 1.**

	Mineral Content			pH	water holding capacity (%)
	N	P	K		
Control	Low	Low	Medium	6.00±0.20	43.00±3.00
Para rubber wood sawdust biochar	Medium	High	Medium	8.00±0.20	85.00±3.00
Rice straw biochar	Low	Medium	High	8.00±0.20	78.00±3.00
Rice husk biochar	Low	Medium	Medium	9.00±0.20	59.00±3.00
Corn leaves and stalks biochar	Low	Medium	High	8.00±0.20	61.00±3.00

Table 1 shows the soil quality and properties of each biochar type.

The results of soil characteristics and nutrient contents before and after rice cultivation in each treatment

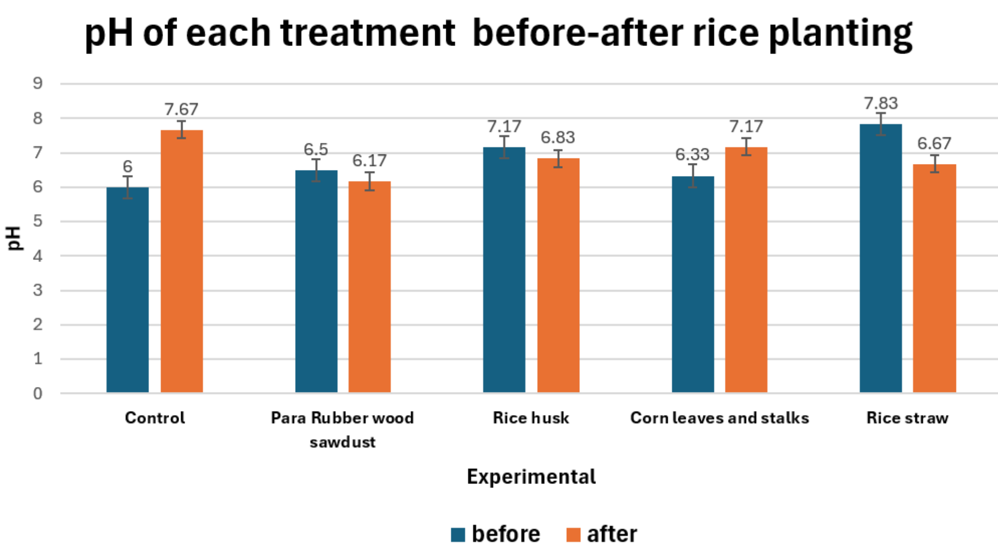
According to **Table 2**, the soil texture of most experimental treatments was clay loam, except for the control treatment, which was silty clay loam. After the experiment, changes in major soil nutrient contents varied depending on the type of material applied. Treatments amended with Para rubber wood sawdust, corn leaves and stalks, and rice straw showed increases in nitrogen and phosphorus contents, whereas potassium content exhibited only slight changes compared to pre-experimental levels. Overall, the application of organic materials improved soil fertility more effectively than the control treatment.

treatment	Soil texture	Nutrient content					
		N		P		K	
		before	after	before	after	before	after
Control	Silty clay loam	Low	Low	Low	Low	Medium	Medium
Para rubber wood sawdust	Clay loam	Medium	High	High	Medium	Medium	High
Rice husk	Clay loam	Low	Low	Medium	Medium	Medium	Medium
Corn leaves and stalks	Clay loam	Low	Medium	High	Medium	High	High
Rice straw	Clay loam	Low	Medium	Medium	High	High	Medium

Table 2 shows the soil characteristics and mineral contents of each treatment.

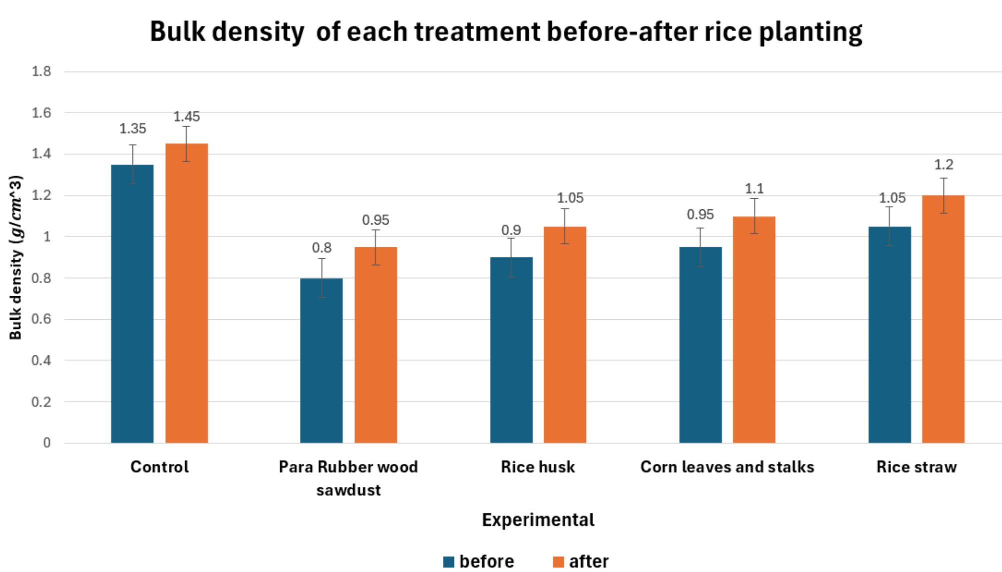
The result of soil properties before and after rice cultivation in each treatment

The results indicated that biochar amendment had a clear effect on soil properties. As shown in **Picture 5**, soil pH before rice cultivation in the biochar-amended treatments increased to a range of 6.33–7.83. After cultivation of Hom Hua Bon rice, soil pH in all treatments fell within the optimal range for rice growth, approximately 6.17–7.67. As shown in **Picture 6**, prior to rice cultivation, soils amended with biochar exhibited lower bulk density, ranging from 0.80 to 1.05 g/cm^3, indicating a more porous soil structure. After rice cultivation, bulk density increased in all experimental treatments. Furthermore, as shown in **Picture 7**, biochar amendment significantly enhanced the water-holding capacity of the soil. Before rice cultivation, biochar-amended treatments exhibited water-holding capacity values of 50.00–65.00%, which were higher than those of the control. After rice cultivation, the treatment amended with para rubber wood sawdust biochar showed the highest water-holding capacity, reaching 85.00 ± 6.00%



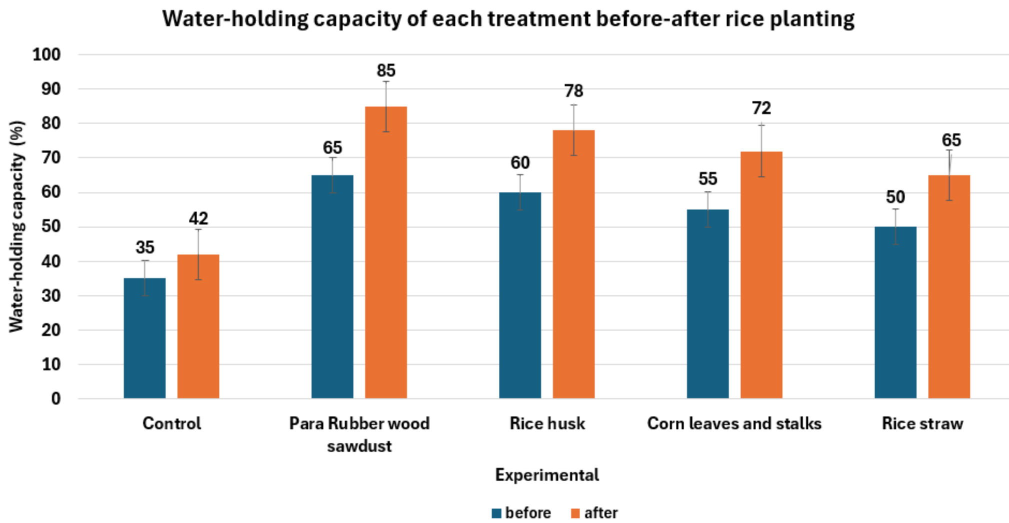
Note * There was no statistical difference at 95% confidence ($p > 0.05$).

Picture 5 compares pH values before-after rice planting for each treatment.



Note * There was statistical difference at 95% confidence ($p < 0.05$).

Picture 6 compares bulk density before-after rice planting for each treatment.

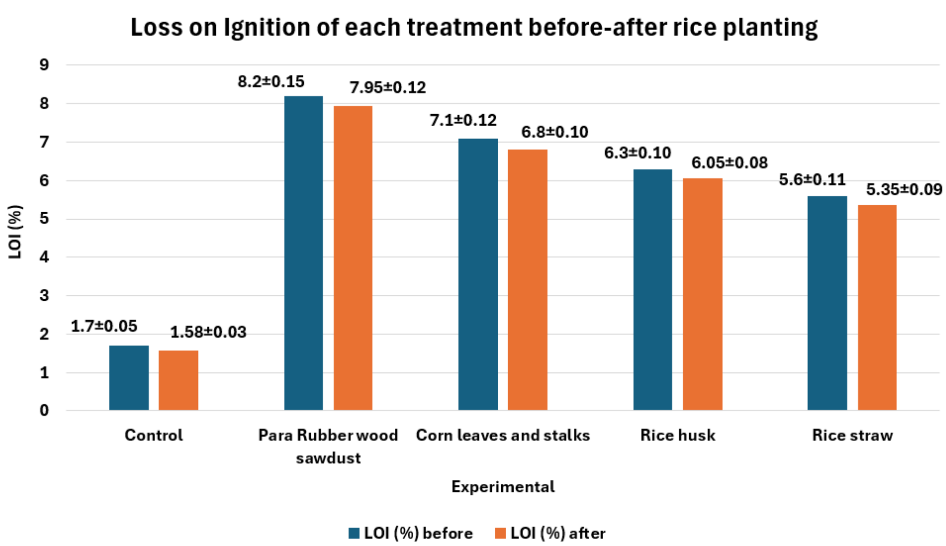


Note * There was statistical difference at 95% confidence ($p < 0.05$).

Picture 7 shows the water holding capacity before-after rice planting for each treatment.

The results of Loss on Ignition before and after rice cultivation in each treatment

The results showed that soil organic matter content tended to decrease after the cultivation of Hom Hua Bon rice in all treatments. The biochar-amended treatments had clearly higher soil organic matter content than the control treatment. Among them, the Para rubber wood sawdust treatment showed the highest values, with 8.20 ± 0.15% before planting and 7.95 ± 0.12% after planting, while the other treatments showed a slight decrease after rice cultivation, as shown in **Picture 8**.

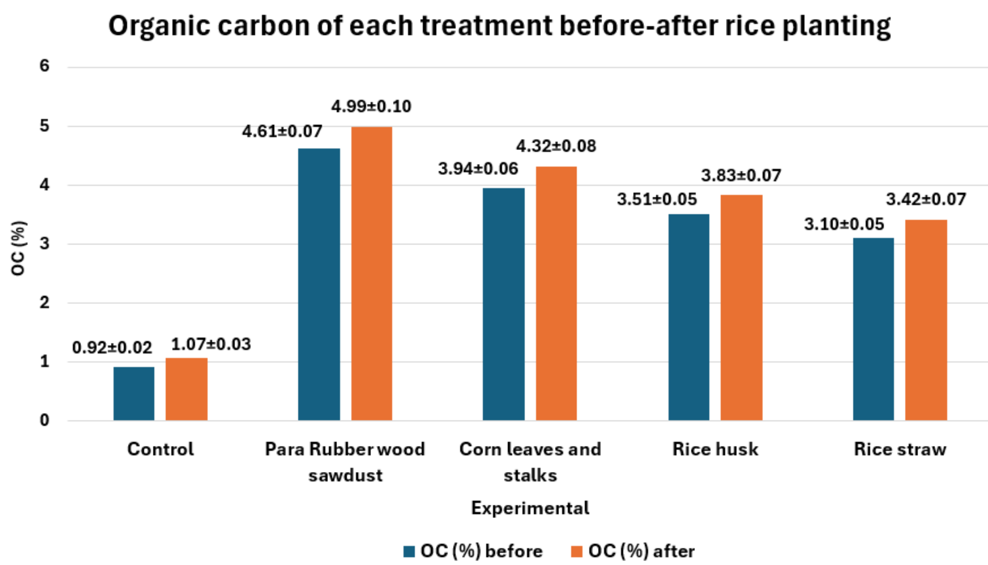


Note * There was statistical difference at 95% confidence ($p < 0.05$).

Picture 8 compares soil organic content before-after rice planting for each treatment.

The results of soil carbon content before and after rice cultivation in each treatment

The results of soil carbon content before and after the cultivation of Hom Hua Bon rice showed that soil carbon content increased after rice cultivation in all treatments. The biochar-amended treatments had clearly higher soil carbon content than the control treatment. Among them, the Para rubber wood sawdust treatment showed the highest values, increasing from 4.61 ± 0.07% to 4.99 ± 0.10%. The Corn leaves and stalks, Rice husk, and Rice straw treatments showed increases in soil carbon content from 3.10–3.94% to 3.42–4.32% after rice cultivation, as shown in **Picture 9.**

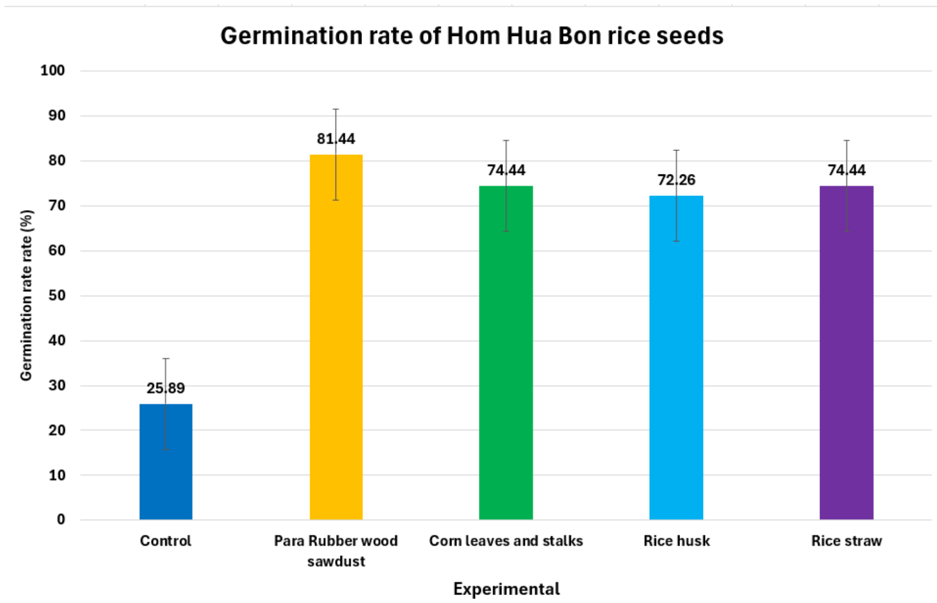


Note * There was statistical difference at 95% confidence ($p < 0.05$).

Picture 9 compares soil carbon content before-after rice planting for each treatment.

The results of germination rate of Hom Hua Bon rice seeds in each soil treatment

The results showed that the germination rate of rice varied among the experimental treatments, as shown in **Picture 10**. The Control treatment showed the lowest germination rate at 25.89 ± 0.50%. In contrast, the treatments amended with organic materials showed higher germination rates than the control. The Para rubber wood sawdust treatment showed the highest germination rate at 81.44 ± 0.50%, followed by the Corn leaves and stalks and Rice straw treatments with germination rates of 74.44 ± 0.50%, and the Rice husk treatment with a germination rate of 72.26 ± 0.50%, respectively.

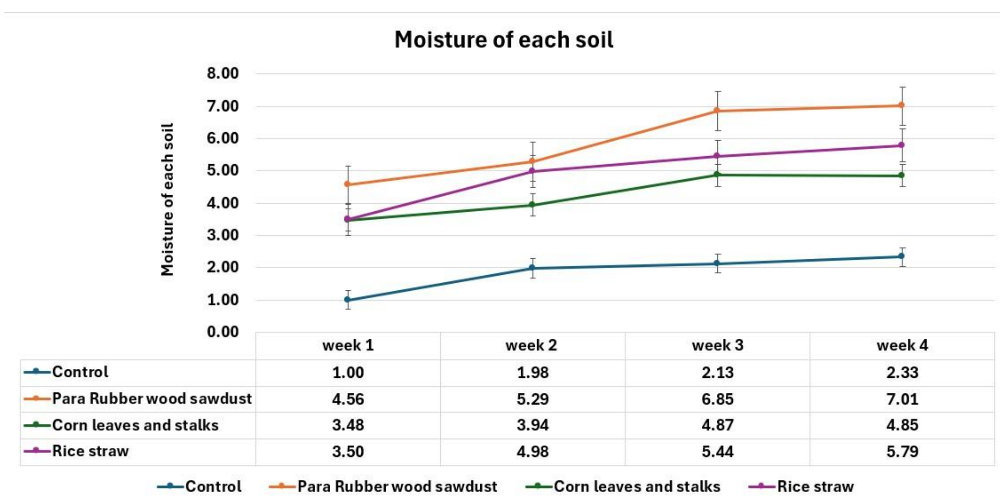


Note * There was statistical difference at 95% confidence ($p < 0.05$).

Picture 10 shows the germination rate of Hom Hua Bon rice seeds in each treatment.

The results of soil moisture content in each treatment over 4 weeks

The results showed that soil moisture tended to increase over the experimental period in all treatments, as shown in **Picture 11**. The Control treatment consistently exhibited the lowest soil moisture throughout the experiment. The biochar-amended treatments showed clearly higher soil moisture than the control. Among them, the Para rubber wood sawdust treatment showed the highest soil moisture throughout the experiment, increasing from 4.56 ± 0.12 to 7.01 ± 0.41. In contrast, the Corn leaves and stalks, Rice husk, and Rice straw treatments showed increases in soil moisture ranging from 3.48–3.50 to 3.89–5.79 by week 4.

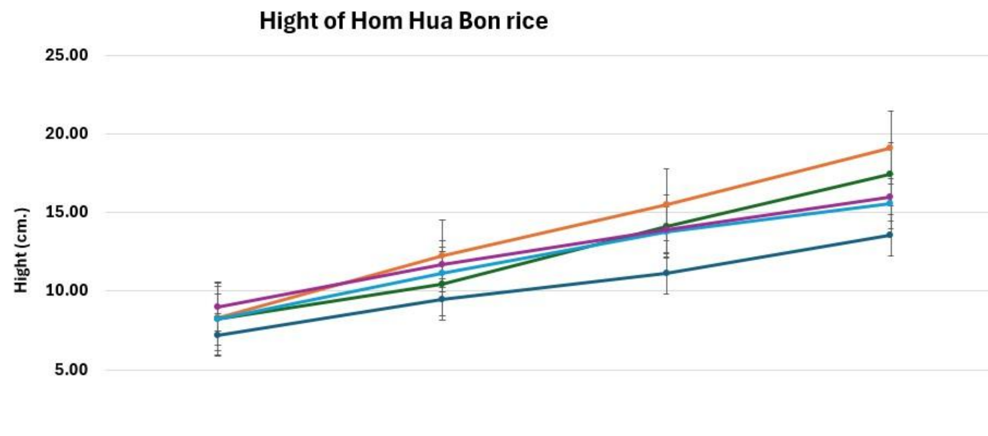


	week 1	week 2	week 3	week 4
Control	1.00	1.98	2.13	2.33
Para Rubber wood sawdust	4.56	5.29	6.85	7.01
Corn leaves and stalks	3.48	3.94	4.87	4.85
Rice straw	3.50	4.98	5.44	5.79

Figure 11 shows soil moisture in each treatment over 4 weeks.

The results of plant height of Hom Hua Bon rice over 4 weeks

The results showed that soil moisture tended to increase over the experimental period in all treatments, as shown in **Picture 12**. The Control treatment consistently exhibited the lowest soil moisture throughout the experiment. The biochar-amended treatments showed clearly higher soil moisture than the control. Among them, the Para rubber wood sawdust treatment showed the highest soil moisture throughout the experiment, increasing from 4.56 ± 0.12 to 7.01 ± 0.41. In contrast, the Corn leaves and stalks, Rice husk, and Rice straw treatments showed increases in soil moisture ranging from 3.48–3.50 to 3.89–5.79 by week 4.



	week 1	week 2	week 3	week 4
Control	7.20	9.47	11.14	13.56
Para Rubber wood sawdust	8.28	12.25	15.50	19.12
Corn leaves and stalks	8.26	10.47	14.10	17.44
Rice husk	8.20	11.17	13.80	15.55
Rice straw	8.99	11.70	13.90	15.96

Figure 12 shows the height of Hom Hua Bon rice plants in each treatment over 4 weeks.

Discussion

The results of the study on the use of biochar from agricultural waste revealed that the type of biochar significantly affected soil properties and carbon sequestration ($P < 0.05$); the application of biochar helped reduce soil bulk density while increasing water holding capacity, soil organic matter, and soil carbon content compared to the control group, although soil pH levels before and after the experiment showed no statistically significant difference ($P > 0.05$) despite an increasing trend within the optimal range for rice growth. Furthermore, it was found that Para rubber wood sawdust biochar was the most effective in improving soil properties, yielding significantly higher water holding capacity, organic matter, and soil carbon than other types of biochar ($P < 0.05$), a difference likely attributed to the variations in chemical composition and porous structure of the biochar which influence water and nutrient retention in the soil. Regarding the growth of Hom Hua Bon rice, the germination rate, soil moisture, and plant height differed significantly across the experimental groups ($P < 0.05$), with the group treated with Para rubber wood sawdust biochar exhibiting the best growth performance, which correlates with its superior ability to retain water and maintain soil nutrients compared to other biochar types.

Conclusion

The conclusion from the study, "Effects of Biochar on Soil Properties, Soil Carbon Sequestration, and the Growth of Hom Hua Bon Rice," shows that biochar produced from Para rubber wood sawdust is the most suitable for rice cultivation. This treatment provided the highest water holding capacity of 85.00 ± 6.00% and the highest soil carbon content after rice cultivation at 4.99 ± 0.10%, while the control treatment showed lower values of 42.00 ± 4.00% for water holding capacity and 1.07 ± 0.03% for soil carbon content.

Statistical analysis showed that soil properties, including bulk density, water holding capacity, organic matter content, and soil carbon content, were significantly different from the control treatment ($P < 0.05$). However, soil pH did not show a significant difference among treatments ($P > 0.05$) and remained suitable for rice growth.

In terms of rice growth, the Para rubber wood sawdust biochar treatment showed the highest germination rate (81.44 ± 0.50%) and the tallest rice plants at week 4 (19.12 ± 1.19 cm), while the control treatment showed the lowest germination rate (25.89 ± 0.50%) and plant height (13.56 ± 0.56 cm). These differences were statistically significant ($P < 0.05$).

According to the results, biochar from Para rubber wood sawdust most effectively improves soil properties, increases soil carbon sequestration, and promotes the growth of Hom Hua Bon rice. Therefore, biochar has strong potential as a soil amendment for sustainable agriculture.

Acknowledgements

We would like to thank our teacher, Mrs. Salamiyah Kittibunyatiwakorn, for her guidance and support throughout this research. We would also like to sincerely thank the rice farmers in Khok Saba Sub-district, Nayong District, Trang Province, for providing Hom Hua Bon rice seeds and valuable information related to rice cultivation. In addition, we would like to thank Princess Chulabhorn Science High School Trang for providing the area and facilities for rice planting and conducting the experiment. Finally, we would like to thank everyone who supported and helped us successfully complete this research.

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GLOBE’s Database

Picture 10 : GLOBE’s Database

(Optional) Badge Descriptions/Justifications

I am a problem solver

This report addresses the issues of soil degradation, reduced rice yield, and carbon emissions by designing an experiment to investigate the effects of biochar on soil properties, soil carbon sequestration, and the growth of Hom Hua Bon rice. The study demonstrates systematic problem-solving skills and the practical application of sustainable soil management.

I am a data scientist

This study is based on the collection and analysis of experimental data using different application rates of biochar. Key soil properties and rice growth parameters were measured, calculated, and compared across treatments, with results presented in tables and graphs to provide evidence-based conclusions that address the research questions.

I make an impact

This research responds to the challenges of soil degradation and climate change by applying biochar produced from agricultural waste to reduce reliance on chemical fertilizers, enhance soil carbon sequestration, and promote the growth of Hom Hua Bon rice. The findings contribute to sustainable agricultural practices and environmental protection.

I am a collaborator

This project was a collaborative effort between students and local rice farmers in Khok Saba Sub-district, Nayong, Trang Province, Thailand. The farmers actively participated in soil preparation, biochar application, rice cultivation, and data collection. This collaboration highlights the importance of partnerships between educational institutions and local communities in achieving scientific and practical outcomes.