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Effect of Biochar on Red Chili Growth and Production in Heavy Acid Soil

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The addition of biochar to soil has been suggested as an environmentally friendly method to enhance soil properties and carbon sequestration and plant production; however, the effects of biochar on root growth and crop production in heavy acid soil is not fully understood. This study evaluated the effects of corn cob biochar on the growth and production of red chili (*Capsicum annuum* L.) in heavy acid soil in Thailand. The soil properties, aboveground and belowground biomasses, fruit dry weight, and fine root length growth and senescence were compared between two biochar conditions, B1 (6.25 t ha^{-1}) and B2 (12.5 t ha^{-1}), and a heavy acid soil control (CF). The soil properties, measured as % organic matter, % organic carbon, and pH, increased in heavy acid soil after applying corn cob biochar. The average aboveground biomass in the CF, B1, and B2 soils was 2,033 ± 1,507, 3,519 ± 1,504, and 3,779 ± 2,469 kg dry matter ha^{-1}, and their average belowground biomass was 806 ± 322, 1,419 ± 513, and 1,288 ± 490 kg dry matter ha^{-1}. The red chili yield in the CF, B1, and B2 soils was 1,497 ± 106, 2,268 ± 28, and 2,204 ± 48 kg dry matter ha^{-1}. The total biomass, root dynamics, and yield in the biochar treatments (B1 and B2) were significantly different ($p < 0.05$) than CF. These results indicate that biochar can improve and stimulate red chili plant growth and crop production in heavy acid soil.

1. Introduction

Thailand is one of the world’s leading agricultural exporters, providing a variety of staple foods, including rice, corn, soybeans, chilis, and fruits. With rising populations and growing pressure on available land resources, farmers are now attempting to cultivate areas that cannot sustain agricultural production without specialized modifications. One of the key areas being exploited are regions with acid soils, which are becoming increasingly common throughout Thailand. There are reportedly an estimated 1.5 million ha of acid sulfate soils in Thailand (Rimwanich and Suebsiri, 1983). The low pH of acid soils tends to be detrimental to plant growth and production because it decreases the availability of macronutrients.

Extensive research using green technology has focused on identifying methods to improve soil properties. For example, Khamis et al. (2017) reported the use of *Rhodopseudomonas palustris* bacteria to reduce soil acidity. There is also growing interest in the use of black (organic) carbon as a green soil additive (Topoliantz et al., 2005). Organic carbon is suggested to enhance soil properties and quality and improve plant productivity by increasing the soil pH and long-term carbon storage and decreasing greenhouse gas emissions associated with the production of certain crops. For example, Hanpattanakit et al. (2017) reported that the addition of biochar to the heavy acid soil of rubber tree plantations in Khon Kaen, Northeast Thailand could increase its pH, % organic matter, and % organic carbon. A recent study by Vijayanathan et al. (2019) found that a combined treatment of controlled-release fertilizer, compost, and biochar could increase the vegetative growth, biomass, and total phenolic content of the medicinal herb *Labisia pumila* compared to NPK fertilization alone. However, biochar treatments have also been observed to negatively affect plant growth. Kishimoto and Sugiura (1985) reported decreased soybean and maize yields using biochar supplementation. Reduced growth or production associated with the use of biochar is generally attributed to decreased N

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availability owing to the high C:N ratio in biochar (Lehmann et al., 2003), or changes in microbial community and enzyme activities in soil (Rondon et al., 2007) or increased soil pH (Kishimoto and Sugiura, 1985).

Red chili (*Capsicum annuum* L.) plays a vital role in Thailand's economy, accounting for approximately 1,583 M THB/y of its export earnings. Red chili is relatively insensitive to soil pH, favoring its use in acidic soils, and chili farming in Thailand has increased by approximately 16,384 ha. However, chili production is still limited by low soil fertility and sub-optimal chemical and physical soil conditions. The potential of biochar to improve soil fertility and increase the growth and production of red chili is the great value to Thailand. Unfortunately, there is limited information regarding the effects of biochar on red chili belowground fine root growth and crop production in heavy acid soil. To determine the benefits of biochar for red chili farming, this study investigated the effects of corn cob biochar treatment on the soil properties of heavy acid soil and its impact on the fine root growth, plant growth, and yield of red chili in Nakhon Nayok province, Central Thailand.

2. Materials and methods

2.1 Site description

A site study was performed in Amphur Ongkarak, Nakhon Nayok province, Central Thailand from February – July of 2017. The experimental site was located at 14°7′17″N and 101°0′14″E in the Botanical Learning Center of the Faculty of Environmental Culture and Ecotourism, Srinakharinwirot University, Ongkarak campus (Figure 1).

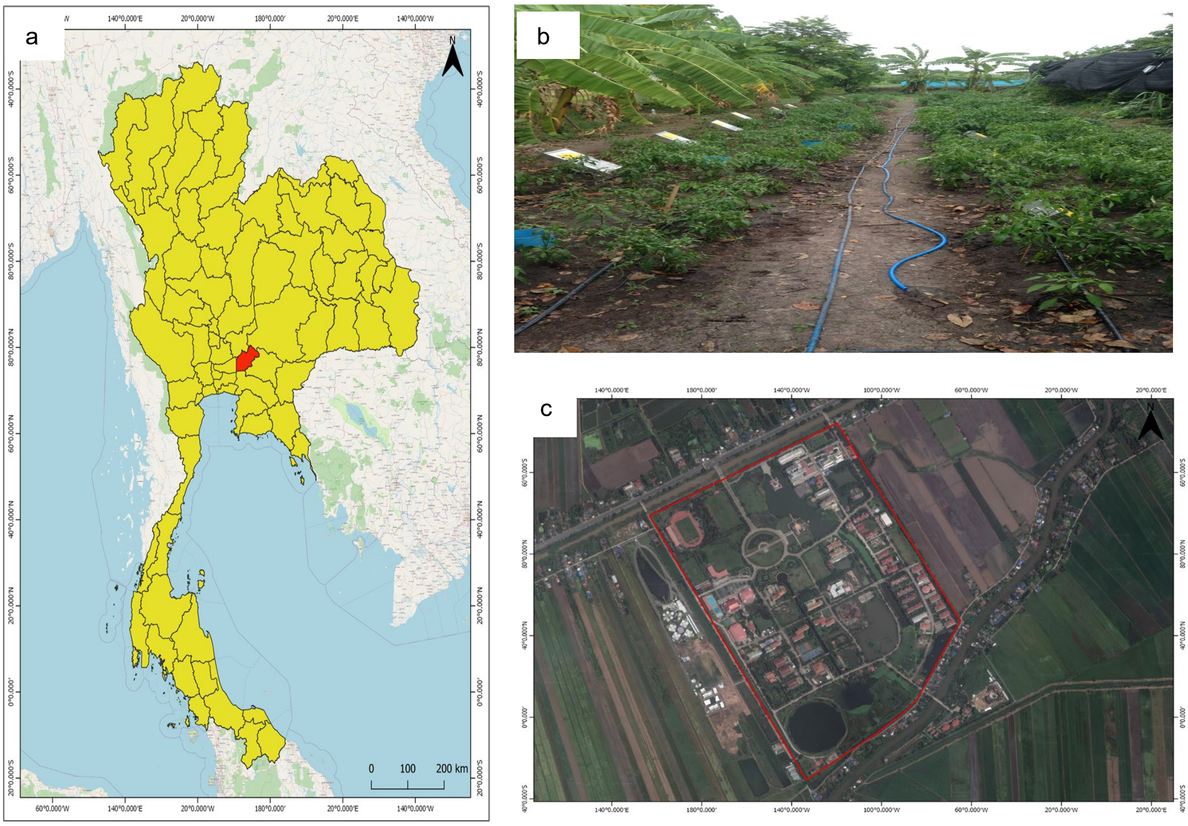

Figure 1: (a) Location of the study site in Amphur Ongkarak, Nakhon Nayok province, Central Thailand, Field, (b) layout of chili plantation applied with biochar in the Botanical Learning Center of the Faculty of Environmental Culture and Ecotourism at 14°7'17"N and 101°0'14"E and (c)site view

2.2 Biochar preparation

Biochar was produced from corn cob at Phetchabun province, Thailand. The pre-carbonization phase was initiated at 50 °C followed by a gradual increase to 300 °C over 50 min under limited oxygen conditions. The temperature was then raised to 350 °C and held for 45 min. The biochar was then mashed, sifted through a stainless-steel soil sieve (diameter: 2 mm), and added to the heavy acid soil in the outdoor plot experiment. The biochar composition was 23.14 % organic carbon and 39.9 % organic matter with a pH of 7.4 (1:1 H_2O).

2.3 Experimental set-up

Experiments were performed using a randomized complete block design with three replicates/treatment. The treatments involved a combination of biochar and manure fertilizer as follows: (i) pure acid soil (no fertilizer or biochar) (control; CF), (ii) addition of 4 t ha^{-1} manure fertilizer and 6.25 t ha^{-1} biochar (B1), and (iii) addition of 4 t ha^{-1} manure fertilizer and 12.5 t ha^{-1} biochar (B2). The manure fertilizer was added to the soil of each crop twice (January and March), while the biochar was added once before beginning the experiment. The chili seeds were germinated in a greenhouse until 8–10 true leaves had developed and then transplanted into the outdoor plot. Each outdoor plot was 2 × 2 m (length × width) and contained 25 trees. The seedlings were grown under 70 % shade for 50 d.

2.4 Plant growth and crop production

Data were collected for plant height (from the soil surface to leaf-top) and number of fruits/tree. Chilis were counted weekly and were included in the count when 80 % of the pepper had become red (from 77–102 d after transplanting outdoors). The plants were oven-dried at 80 °C for 48 h or until a constant weight was obtained. All plants were weighed before and after drying.

2.5 Root measurement

Root growth and senescence were monitored using minirhizotron techniques (Maeght et al., 2013). This method is widely used across multiple fields of root research, including investigations into root distribution, root demography, and interactions at the root-soil interface. Scanning boxes (40 × 100 cm; width × height) were prepared for all site plots. Each scanning box was specially designed with a stainless-steel support bearing 1 cm thick glass and inserted into the soil at a 45° angle (Figure 2). The scanning plot was prepared after broadcasting a red chili tree into the outdoor plot. Nine images were obtained across the triplicate treatments each week. Each image was analyzed for root length, growth, and death using GIMP 2.6 (free online software) and WinRHIZO Basic (Regent Instruments Inc., Quebec, Canada). GIMP 2.6 was used to draw the line of fine root growth and senescence to enable determination of the root width and length with WinRHIZO.

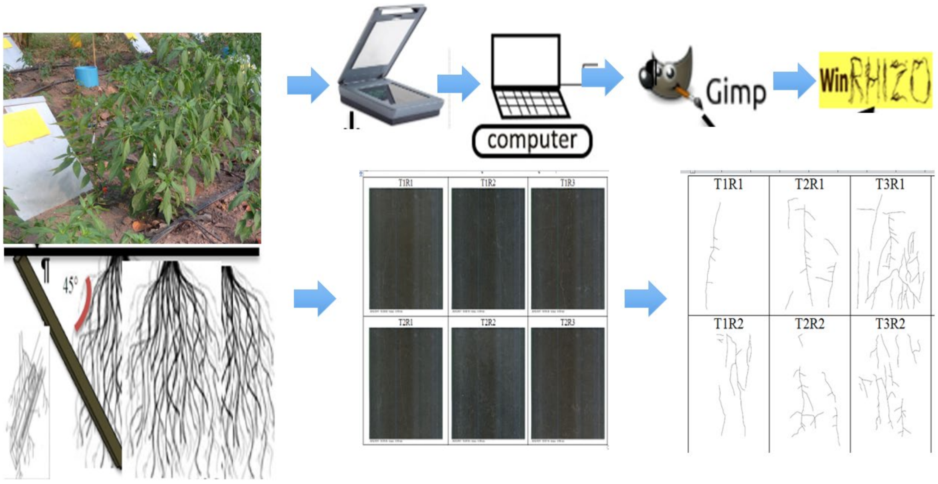

Figure 2: Schematic diagram of fine root measurement using minirhizotron techniques.

2.6 Soil properties analysis

2.6.1 Organic carbon and organic matter

Organic matter and organic carbon content in the soil were determined using the Walkley-Black method (Walkley and Black, 1934). Organic carbon was converted into % organic carbon using Eq(1) (Office of Science for Land Development, 2004). The cation exchange capacity (CEC) and total N, P, K, Ca, Mg, Fe, and Al compositions of both the soil and biochar were measured prior to the experiment (Table 1).

$$\%\ \text{Organic matter} = \%\ \text{Organic carbon} \times 1.724 \quad (1)$$

2.6.2 Soil pH

Soil pH was measured in a 1:1 soil:water suspension using a glass electrode pH meter. Air-dried soil samples were sifted through a 2 mm sieve prior to suspension.

2.7 Statistical analysis

One-way analysis of variance was performed to determine significant differences between treatments. The significant effects of the various treatments were analyzed using statistical software package SPSS 20.

3. Results and discussions

3.1 Effects of biochar on soil properties

The initial chemical characteristics of the heavy acid soil and corn cob biochar were analyzed (Table 1). The corn cob biochar had a notably higher pH (10.43) and CEC (43.33 cmolc kg^{-1}) than the heavy acid soil (4.10 and 34.20 cmolc kg^{-1}. The biochar also had a greater N concentration than the heavy acid soil, although neither P nor K was detected in the biochar. The Ca, Mg, Fe, and Al elemental compositions of the acid soil were higher than in the corn cob biochar. The high metal composition is a key characteristic of acid soil.

Table 1: Chemical characteristics in the heavy acid soil and the corn crob biochar prior to experiment

Property	Heavy acid soil	Corn cob biochar	Method
pH (1:5 H_2O)	4.10	10.43	Glass-electrode pH meter
CEC (cmol$_c$kg^{-1})	34.20	43.33	NH_4OAc pH 7.0
Total N (%)	0.17	0.61	KCl extraction, Distillation
Total P (%)	0.03	nd	Bray II extraction, UV-VIS spectroscopy
Total K (%)	0.73	nd	Atomic absorption/flame spectrophotometer
Total Ca (g kg^{-1})	1.61	1.00	Atomic absorption/flame spectrophotometer
Total Mg (g kg^{-1})	2.61	1.30	Atomic absorption/flame spectrophotometer
Total Fe (g kg^{-1})	28.54	0.37	Atomic absorption/flame spectrophotometer
Total Al (g kg^{-1})	89.10	0.19	Atomic absorption/flame spectrophotometer

The pH of the acid soil increased with increasing quantities of corn cob biochar (Table 2). At the end of the experiment, the average pH of the biochar-treated acid soil had increased by 10 % and 18 % for the B1 (6.25 t ha^{-1} biochar) and B2 (12.5 t ha^{-1} biochar) treatments, compared to the pure acid soil (CF). This aligns with work from Dharmakeerthi et al. (2012), who observed an approximate 1 unit increase in acid soil pH using timber mill waste charcoal. Nurhidayati and Mariati (2014) reported similar findings, observing a 23 % increase in the biochar-treated soil pH of a sweet maize plantation, which was attributed to a reduction in exchangeable Al^{3+}.

Increasing quantities of biochar were also found to increase the % organic matter (% OM) and % organic carbon (% OC) of the acid soil (Table 2). The functional groups of organic matter in soil can be either positively or negatively charged depending on the soil pH, which affects the ability of the soil to adsorb cations (Havlin et al., 2005). Glaser et al. (2002) suggested that the addition of organic matter-derived supplementations to acid soil could increase the CEC and decrease heavy metal toxicity of the soil. The results of this study indicate that biochar can improve acid soil properties (pH, % OM, and % OC) to the levels needed to support plant growth.

Table 2: Mean ± standard deviation of pH, % organic matter (OM), and % organic carbon (OC) of chili plantation acid soil.

Treatments	pH		% Organic matter (% OM)		Organic carbon (% OC)	
	Mean	± SD	Mean	± SD	Mean	± SD
Pure acid soil: CF1	4.73	0.21	0.54	0.09	0.31	0.05
Biochar 6.25 t ha^{-1}: B1	5.23	0.29	0.63	0.15	0.37	0.08
Biochar 12.5 t ha^{-1}: B2	5.60	0.42	0.79	0.27	0.46	0.16

3.2 Effects of biochar on plant growth and crop production

The aboveground biomass, belowground biomass, and red chili production differed significantly ($p < 0.05$) between the treated and untreated soils (Table 3). Both B1 and B2 biochar treatments resulted in increased biomass and crop production compared to CF, although plant height was not significantly affected (Table 3).

While the yield of red chili was significantly greater for the biochar-treated soil than in CF (1,497 kg dry matter ha^{-1}), there was minimal difference between the B1 and B2 treatments (2,268 and 2,204 kg dry matter ha^{-1}), indicating that larger quantities of biochar do not substantially affect crop yield. The findings of this study indicate that biochar can enhance the ability of plants to grow in acid soil. This is likely due to biochar's effects on acid soil properties, including increasing the pH, CEC, % OC, and % OM (Table 2). These changes enhance the soil's ability to retain and transfer nutrients. This agrees with the findings of Uzoma et al. (2011), who showed that the addition of biochar to sandy soil could enhance the nutrient uptake and yield of maize.

Table 3: Effects of biochar treatment on red chili growth, yield, and aboveground and belowground biomass.

Treatments	Height (cm)		Yield (kg/ha)		Aboveground biomass (kg/ha)		Belowground biomass (kg/ha)	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
CF	53.14	± 20.21	1,497	±106^{a}	2,033	± 1,507^{a}	806	± 322^{a}
B1	53.95	± 19.00	2,268	±28^{b}	3,519	± 1,504^{b}	1,419	± 513^{b}
B2	60.37	± 23.04	2,204	±48^{b}	3,779	± 2,469^{b}	1,288	± 490^{b}
Level of Sig.0.05	NS		*		*		*	

3.3 Effects of biochar on fine root length

The morphological characteristics of chili plants, particularly the root system, play an important role in the uptake of water and nutrients from the soil. The root growth and senescence differed significantly ($p < 0.05$) between the biochar-treated and untreated soils (Figure 3). The accumulated root growth for the entire crop season was 1,741 ± 53.98, 1,566 ± 27.99, and 1,459 ± 21.18 km ha^{-1} crop^{-1} for B1, B2, and CF. The accumulated root senescence was 289 ± 4.67, 266 ± 4.86, and 247 ± 2.85 km ha^{-1} crop^{-1} for B1, B2, and CF. The weekly pattern of fine root growth was similar across all treatments between day 1 and 46; however, the root growth rate then increased for B1 and B2 crops. Root senescence was generally lower for CF than either of the biochar conditions (Figure 3). There are deleterious effects on root growth when soils acidify and generate toxic levels of Al and Fe (Table 1). For example, toxic levels of Al^{3+} in soil affect root cell division and root elongation. Root tips that are deformed and brittle result in poor root growth and branching, subsequently affecting plant growth (Xiang et al., 2017). Roots are unable to effectively grow through acidic subsurface soil, which forms a barrier and restricts access to subsoil water used for grain filling. This study found that biochar treatments could enhance the fine root elongation of red chili growing in heavy acid soil, likely due to biochar's effects on soil properties (Table 2). This enhanced fine root elongation in turn stimulates plant growth and crop production (Table 3).

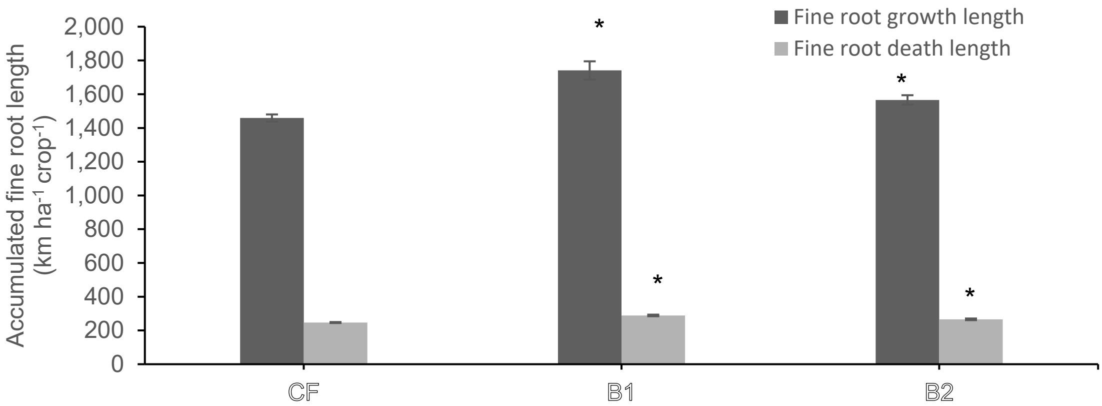

Figure 3: Accumulation of fine root growth and death in heavy acid (CF) and biochar-treated (B1 and B2) soils.

4. Conclusions

The addition of corn cob biochar to acid soil can improve soil fertility by increasing soil pH, which increases nutrient availability. Biochar treatments B1 (6.25 t ha^{-1} biochar) and B2 (12.5 t ha^{-1} biochar) were found to increase the pH of acid soil by 10 % and 18 %, compared to the untreated control. This increase in soil pH also increased the availability of OM and OC. The beneficial effects of biochar treatment were displayed through increased aboveground and belowground biomasses and red chili production. The average aboveground biomass in the CF, B1, and B2 soils was 2,033 ± 1,507, 3,519 ± 1,504, and 3,779 ± 2,469 kg dry matter ha^{-1}, and their average belowground biomass was 806 ± 322, 1,419 ± 513, and 1,288 ± 490 kg dry matter ha^{-1}. The red chili yield in the CF, B1, and B2 soils was 1,497 ± 106, 2,268 ± 28, and 2,204 ± 48 kg dry matter ha^{-1}. These results indicate that biochar can improve plant growth, root elongation, and crop production in heavy acid soils. This study strongly supports the use of biochar from crop residuals as a sustainable and environmentally friendly technology to improve heavy acid soil properties allowing for increased crop production.

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