อิทธิพลของเวลาในการใช้ถ่านแกลบต่อไนโตรเจนอนินทรีย์ในดินและการเจริญเติบโตของข้าว

Effects of Timings in Rice Husk Charcoal Application on Soil Inorganic Nitrogen and Rice Growth

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Abstract: The investigation of the proper timing of applying rice husk charcoal (RHC) to improve soil inorganic nitrogen (N) and rice growth is still limited. This paper, therefore, aimed to examine the effects of various timings of RHC (involving unamended and different timings of RHC application as in inversely chronological order varied from the late to early applications as 0, 15, 30, and 60 days before rice transplanting) on soil NH_4^+–N and NO_3^-–N concentrations and rice growth in a loamy paddy soil of Northeast Thailand. On the rice transplanting date, the earlier application of RHC brought about lower NH_4^+–N but higher NO_3^-–N concentrations than the later counterparts, indicating that the earlier charcoal application rendered a more extended transformation of NH_4^+ to NO_3^-. Because rice preferred NH_4^+ over NO_3^-, this effect led to less rice growth in the earlier than later applications of RHC before the rice transplanting. Therefore, the application of RHC into a loamy paddy soil on the date of rice transplanting was recommended to manipulate proper concentrations of soil inorganic N for maximizing rice growth.

Keywords: Biochar, Mineral nitrogen, Nitrification, Nitrogen transformation, Paddy soil

บทคัดย่อ: การศึกษาเวลาที่เหมาะสมในการใช้ถ่านแถลบในการปรับปรุงไนโตรเจนอนินทรีย์ในดินและการเจริญเติบโตของข้าวยังมีอยู่อย่างจำกัด บทความนี้จึงมีวัตถุประสงค์เพื่อศึกษาอิทธิพลของเวลาที่แตกต่างกันของการใช้ถ่านแกลบ (ซึ่งประกอบด้วย ไม่ใส่ถ่านแกลบ และใส่ถ่านแกลบในเวลาที่แตกต่างกันก่อนการปักดำข้าว โดยมีลำดับการใช้ตามเวลาจากการใส่ช้าไปใส่เร็ว คือ 0, 15, 30, และ 60 วันก่อนปักดำ) ต่อความเข้มข้นของ NH_4^+–N และ NO_3^-–N ในดินและการเจริญเติบโตของข้าวที่ปลูกในดินนาเนื้อร่วนของภาคตะวันออกเฉียงเหนือของประเทศไทย ณ วันที่ทำการปักดำ พบว่าการใส่ถ่านแกลบในช่วงเวลาที่เร็วกว่าทำให้มีความเข้มข้นของ NH_4^+–N ต่ำกว่า แต่ NO_3^-–N สูงกว่า เมื่อเปรียบเทียบกับการใส่ถ่านแกลบในช่วงเวลาที่ช้ากว่า แสดงให้เห็นว่าการใส่ถ่านแกลบในช่วงเวลาที่เร็วกว่าทำให้มีการเปลี่ยนรูปของ NH_4^+ เป็น NO_3^- มากกว่า เนื่องจากข้าวชอบ NH_4^+ มากกว่า NO_3^-

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อิทธิพลดังกล่าวนี้จึงทำให้ข้าวมีการเจริญเติบโตน้อยลงเมื่อมีการใส่ถ่านแกลบก่อนการปักดำเร็วขึ้น ดังนั้น จึงแนะนำให้มีการใส่ถ่านแกลบสำหรับดินนาเนื้อร่วน ณ วันที่ทำการปักดำข้าว เพื่อเป็นการจัดการความเข้มข้นที่เหมาะสมของไนโตรเจนอนินทรีย์ในดินเพื่อทำให้ข้าวมีการเจริญเติบโตสูงสุด

คำสำคัญ: ถ่านชีวภาพ, มิเนอรัลไนโตรเจน, ไนทริฟิเคชัน, การเปลี่ยนรูปของไนโตรเจน, ดินนา

Introduction

Paddy soil degradation in Northeast Thailand is of natural and anthropogenic accomplishments (Vityakon, 2007). The RHC is seen as a promising amending material in Thailand since it is produced from a by-product of rice production, creating a massive amount of rice husk (Thambhitaks and Kitchaicharoen, 2021) that is nationwide readily available and practically used. Charcoal used as a soil amendment, termed biochar, is interested in practical use and academic investigation (Latawiec *et al*., 2017). It showed agronomic benefits (Butnan *et al*., 2015) and environmental issue mitigations (Butnan *et al*., 2016). However, certain studies showed no effects of using charcoal as a soil amendment in rice production (Si *et al*., 2018), while some negative outputs were demonstrated (Ly *et al*., 2015). The availability of soil nitrogen (N) might be a critical factor affecting such undesirable outputs. Therefore, the proper time for charcoal application was conceivable of the availability of soil N for rice growth. Unfortunately, the investigation of timings in charcoal application is still limited.

The hypothesis of the current study addressed a general hypothesis that the timings of RHC application would affect the availability of soil N. This study therefore aimed to examine the effects of the timings of RHC application prior to rice transplanting on soil NH_4^+–N and NO_3^-–N concentrations and rice growth in paddy soil of Northeast Thailand.

Materials and Methods

Soil and rice husk charcoal

A soil used in this study was identified as Roi-et series (Fine-loamy, mixed, subactive, isohyperthermic Aeric Kandiaquults), which was classified following the Land Development Department (2021). It was collected from a paddy field in Sakon Nahon province at a depth of 0–15 cm. The soil was air-dried and then sieved through a 2-mm mesh before being employed in the experiment. Soil texture was detected as loam. Soil organic matter and total N were 0.97% and 0.04%, respectively. Concentrations of NH_4^+–N and NO_3^-–N in soil were 8.23 and 12.25 mg/kg, respectively. Soil pH was 4.5, and electrical conductivity was 0.04 mS/cm.

RHC was produced under a kiln modified from a 200-liter metallic tank using a pyrolysis temperature of 450 °C for 2 hours and left to cool down for 6 hours. The charcoal contained 52% fixed carbon, 18% volatile matter, and 30% ash. The pH of the RHC was 6.79, and electrical conductivity was 0.63 mS/cm.

Pot experiment

A pot experiment was conducted under a greenhouse equipped with an evaporative cooling system during June–November 2019. Mean air temperature was 30.8 °C. Different timings of RHC application before rice transplanting (DBT) was evaluated, including i) unamended (No RHC, 0 DBT), and different timings of RHC application in inversely chronological order varied from the late to early applications as follows, ii) 0 (RHC, 0 DBT), iii) 15 (RHC, 15 DBT), iv) 30 (RHC, 30 DBT), and v) 60 (RHC, 60 DBT).

A pot with a volume of 6,823 cm^3 was filled with 6 kg air-dry soil mixed thoroughly with 120 g of RHC equivalent to 2% w/w. The timings of rice husk application were undertaken at times corresponding to the above-aforementioned treatments. Each pot received 1,506 ml of water, equivalent to 70% of the soil water holding capacity till rice transplanting that was later maintained to a 3-cm depth of water until seven days before the rice was harvested. The RD.22 variety rice was seeded and nursed in a nursery tray for 30 DBT. A couple of seedlings were transplanted to each pot. Chemical fertilizer grades 46-0-0, 18-46-0, and 0-0-60 were applied three times to all pots at 3, 20, and 37 days after transplanting (DAT) to obtain 180 kg N/ha, 26.2 kg P/ha, and 74.7 kg K/ha (Sun *et al.*, 2015). Rice was harvested at 98 DAT or 128 days after seeding. The rice results presented herein are only the growth parameters, including height, tillering, leaf area, chlorophyll content. The soil was sampled at 0, 42, and 98 days after rice transplanting or 30, 72, and 128 days after seeding. These fresh soil samples were later used to analyze inorganic (NH_4^+ and NO_3^-) N concentrations.

Plant growth measurement and laboratory analyses

Leaf area determination was undertaken following Butnan and Toomsan (2019). Meanwhile, leaves' chlorophyll content was achieved by using a SPAD chlorophyll meter (SPAD 502 Plus, Spectrum Technologies, Inc., Illinois, USA).

Soil texture was obtained by the pipette method (Kroetsch and Wang, 2008). Soil pH was measured in a soil-to-distilled water of 1:1 w/v (Thomas, 1996), while that of RHC was 1:10 (Singh *et al.*, 2017). Electrical conductivity of soil was measured in a ratio of 1:5 w/v, and that of the charcoal was 1:10 w/v. Soil organic matter was assessed using Walkley and Black (Nelson and Sommers, 1982), while total N was by the Kjeldahl method on a micro-Kjeldahl distillator (Bremner and Mulvaney, 1982). The charcoal's fixed carbon, volatile matter, and ash were determined following the proximate analysis regarding ASTM D7582-15 (American Standard of Testing Material, 2015).

Statistical analysis

One-way analysis of variance based on a completely randomized design using the PROC ANOVA procedure following SAS Institute Inc. (2004) was conducted to estimate the effects of varied timings of RHC application on soil NH_4^+–N and NO_3^-–N concentrations and rice growth. Multiple comparisons were assessed using Fisher's least significant difference test. Significant differences were at $p \leq 0.05$.

Results and Discussion

Earlier application of RHC into the soil prior to rice transplanting brought about the more extended transformation of NH_4^+ to NO_3^- as seen in decreased NH_4^+–N and increased

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NO_3^-–N concentrations on 0 DAT, which was generally more pronounced in the early than the later charcoal applications (Table 1). The result indicated that the earlier applications of RHC rendered more stimulation of the nitrification of this acid soil. Several mechanisms of charcoal stimulating the nitrification were proposed by Prommer *et al*. (2014). First, the alkaline nature of charcoal increased the pH of acid soils, including the very strongly acid soil (pH 4.5) used in this study. Even though the RHC employed in the current study herein was not alkaline (pH 6.79), it raised the pH of the acid soil to nearly neutral thanks to its higher pH, which benefited nitrifiers whose optimal pH ranged from slightly acidic to neutral. Second, charcoal fueled nitrification by providing N for nitrifiers. The premise can be validated by a result shown by Kizito *et al*. (2015), RHC contained 8.9 g N/kg. Third, the high specific surface area and porosity of RHC created a high adsorption capacity of the charcoal for substances that behaved like nitrification inhibitors such as ethylene and acetylene, which originated from the decomposed organic materials. Fourth, since the nitrifying activity was dependent upon oxygen availability, the high porosity of charcoal increased the oxidized condition of the soil. On 0 DAT, the absence of charcoal in nitrification stimulation might explain the higher NH_4^+–N concentration in unamended soil (No RHC, 0 DBT) than in the charcoal treatments (Table 1).

Table 1 Soil NH_4^+–N and NO_3^-–N concentrations as affected by various timings of rice husk charcoal application.

Treatment	NH_4^+–N (mg N/kg)			NO_3^-–N (mg N/kg)		
	0 DAT †	42 DAT	98 DAT	0 DAT	42 DAT	98 DAT
No RHC, 0 DBT †	10.2 a ‡	7.69 a	6.15	1.1 d	1.30 ab	1.32
RHC, 0 DBT	8.9 c	8.11 a	6.09	0.8 d	1.57 a	1.50
RHC, 15 DBT	9.5 b	6.48 b	6.09	8.3 c	1.69 a	1.98
RHC, 30 DBT	5.8 d	6.41 b	5.67	15.2 b	1.09 b	1.20
RHC, 60 DBT	5.6 d	6.89 b	5.88	42.5 a	1.10 b	1.82
p value	<0.001	<0.001	0.953	<0.001	0.030	0.572
F test	***	***	ns	***	*	ns
CV (%)	3.99	3.98	14.31	9.68	17.17	41.84

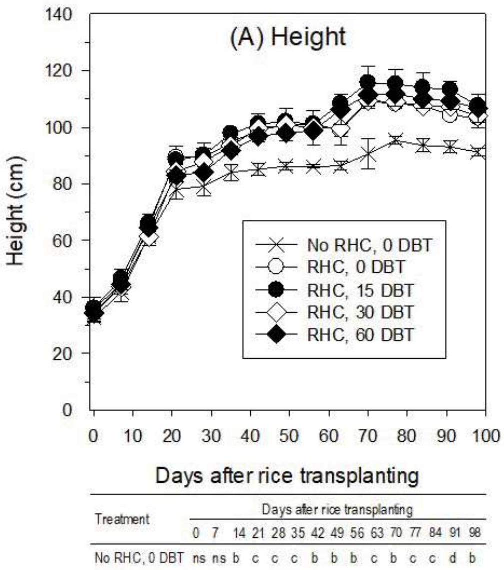
* $p \leq 0.05$; *** $p \leq 0.001$; ns = not significantly different (F test).

† RHC = rice husk charcoal; DAT = days before rice transplanting; DAT = days after rice transplanting.

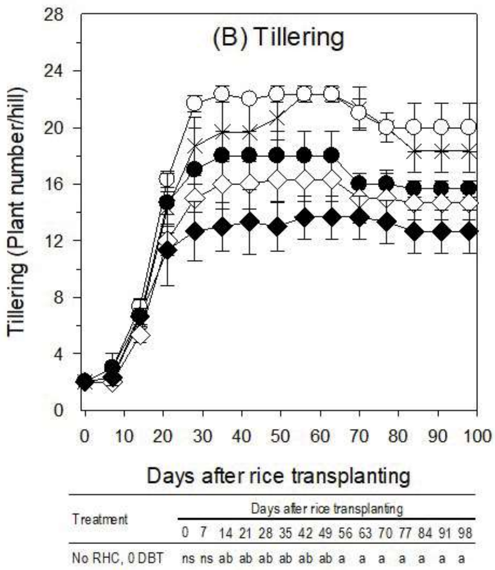
‡ Means within the same column followed by the same letter are not significantly different at $p \leq 0.05$ (Fisher's least significant difference).

Decreased NH_4^+–N and NO_3^-–N concentrations on 42 DAT in the earlier compared to the later charcoal application, and no significant difference in NH_4^+–N and NO_3^-–N on 98 DAT (Table 1) might follow the first-order kinetic (Mohanty *et al*., 2008) of which inorganic N (NH_4^+ and NO_3^-) decreased as a declined urea that was a primary substrate for nitrification of the current study.

The decreases in NH_4^+ concentrations and increases in NO_3^- concentrations brought about a reduction in rice growth. The trends of lower NH_4^+–N concentrations in 0 DAT in the earlier applications of RHC compared to the later application counterparts (Table 1) resulted in decreased rice growth. The general decreases in rice's height (Figure 1A), tillering (Figure 1B), leaf area (Figure 2A), and chlorophyll content (Figure 2B) evidenced the deleterious effect of earlier application of RHC relative to the later application counterparts. Rice generally prefers taking up more NH_4^+ over NO_3^- (Mengel and Kirkby, 2001). According to a critical review of Fageria (2014), rice cultivated in an NH_4^+ solution had a greater shoot and root biomass than that grown in a NO_3^- solution. Fried *et al.* (1965) have put forward that even though rice uses both NH_4^+ and NO_3^- from the soil solution, it uptakes NH_4^+ as fast as 5–20 times as NO_3^- does. The energy needed for NO_3^- uptake is higher than that for NH_4^+ (Fageria *et al*., 2011). After NO_3^- is taken up, the energy was required for the NO_3^- reduction reaction prior to the assimilation and transportation within the rice plant (Fageria, 2014).



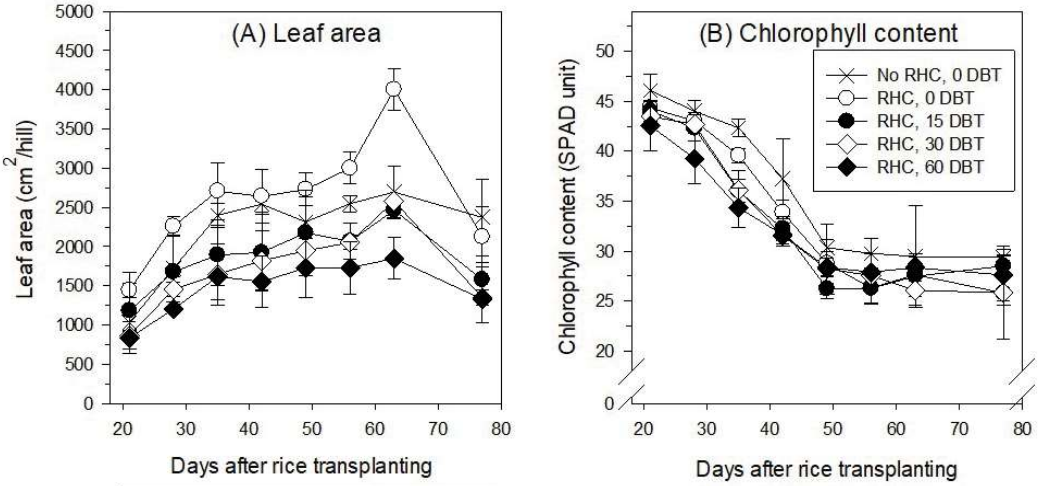
Treatment	Days after rice transplanting														
	0	7	14	21	28	35	42	49	56	63	70	77	84	91	98
No RHC, 0 DBT	ns	ns	b	c	c	c	b	b	b	c	b	c	c	d	b
RHC, 0 DBT	ns	ns	ab	a	ab	ab	a	a	a	b	a	b	b	c	a
RHC, 15 DBT	ns	ns	a	ab	a	a	a	a	a	a	a	a	a	a	a
RHC, 30 DBT	ns	ns	b	ab	ab	b	a	a	a	b	a	b	b	bc	a
RHC, 60 DBT	ns	ns	ab	bc	bc	b	a	a	a	ab	a	ab	ab	ab	a



Treatment	Days after rice transplanting														
	0	7	14	21	28	35	42	49	56	63	70	77	84	91	98
No RHC, 0 DBT	ns	ns	ab	ab	ab	ab	ab	ab	a	a	a	a	a	a	a
RHC, 0 DBT	ns	ns	a	a	a	a	a	a	a	a	a	a	a	a	a
RHC, 15 DBT	ns	ns	a	ab	bc	bc	bc	bc	b	b	b	b	b	b	b
RHC, 30 DBT	ns	ns	b	bc	cd	cd	cd	c	b	b	b	bc	bc	bc	bc
RHC, 60 DBT	ns	ns	a	c	d	d	d	d	c	c	b	c	c	c	c

Figure 1 Height (A) and tillering (B) of the rice plant as affected by various timings of rice husk charcoal (RHC) application. The table accompanying each figure demonstrates comparisons of the application timings at each time interval or each period of day after rice transplanting (DAT). Similar letters within a DAT are not significantly different ($p \leq 0.05$; Fisher's least significant difference test). Vertical bars are the standard deviation.

Nevertheless, the significantly higher NH_4^+ concentrations in unamended soil (No RHC, 0 DBT) relative to the RHC amended soil of the same application date (RHC, 0 DBT) did not generally translate into significantly higher rice growth (Figure 1A, 1B and 2A), except chlorophyll content (Figure 2B). Besides available inorganic nitrogen, i.e., NH_4^+ and NO_3^-, RHC provided other essential elements to the rice plant (Asadi *et al*., 2021). Charcoal constituted vital components that were proven to influence plant growth, i.e., fixed carbon, volatile matter, and ash (Deenik *et al*., 2010; Deenik *et al*., 2011). Among these charcoal components, ash of RHC contained a variety of minerals that are a source of essential elements for the rice plant, e.g., N, P, K, Ca, Mg, and Si (Nwajiaku *et al*., 2018; Asadi *et al*., 2021). These ash-derived elements exhibited both positive and negative effects on plant growth (Deenik *et al*., 2011; Butnan *et al*., 2015). Therefore, the influences of plant nutrients derived from the ash component of RHC ought to be further investigated.



Treatment	Days after rice transplanting							
	21	28	35	42	49	56	63	77
No RHC, 0 DBT	ab	b	ab	ab	ab	b	b	a
RHC, 0 DBT	a	a	a	a	a	a	a	ab
RHC, 15 DBT	ab	b	bc	bc	ab	c	b	bc
RHC, 30 DBT	b	bc	c	c	b	c	b	c
RHC, 60 DBT	b	c	c	c	b	c	c	c

Treatment	Days after rice transplanting							
	21	28	35	42	49	56	63	77
No RHC, 0 DBT	a	a	a	a	a	a	ns	ns
RHC, 0 DBT	ab	a	b	ab	ab	b	ns	ns
RHC, 15 DBT	ab	a	c	b	b	b	ns	ns
RHC, 30 DBT	ab	a	c	b	ab	ab	ns	ns
RHC, 60 DBT	b	b	c	b	ab	ab	ns	ns

Figure 1 Leaf area (A) and leaf chlorophyll content (B) of the rice plant as affected by various timings of rice husk charcoal (RHC) application. The table accompanying each figure demonstrates comparisons of the application timings at each time interval or each period of day after rice transplanting (DAT). Similar letters within a DAT are not significantly different ($p \leq 0.05$; Fisher's least significant difference test). Vertical bars are the standard deviation.

Conclusions

Results of this study showed that the earlier application of RHC into the soil before the rice transplanting brought about a more extended transformation of NH_4^+ to NO_3^- manifesting decreases in rice growth. Applying RHC into a loamy paddy soil on the date of rice transplanting was recommended for proper soil inorganic N concentration to maximize the rice growth in paddy acid soil. However, other soil parameters, particularly ash-derived elements constituted in RHC that potentially affect rice growth, are required to be further investigated.

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