ถ่านแกลบและถ่านแกลบที่ใช้ร่วมกับปุ๋ยเคมีและปุ๋ยอินทรีย์ที่มีอิทธิพลต่อการเจริญเติบโตของข้าวโพดที่ปลูกในดินทรายและดินลูกรัง

Rice Husk charcoal and its Combined Uses with Conventional Chemical and Organic Fertilizers influencing Corn Growth in Sandy and Lateritic Soils

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บทคัดย่อ

การใช้ถ่านแกลบเป็นวัสดุปรับปรุงดินมีศักยภาพในการปรับปรุงความอุดมสมบูรณ์ของดินลูกรังและดินทรายที่เสื่อมโทรม จึงได้ดำเนินการทดลองจำนวน 2 การทดลองภายใต้สภาพโรงเรือน เพื่อประเมินอิทธิพลของถ่านแกลบและการใช้ถ่านแกลบร่วมกับปุ๋ยชนิดอื่น ๆ ที่มีการใช้โดยทั่วไป ซึ่งประกอบด้วย ปุ๋ยเคมี มูลวัว และปุ๋ยหมัก ที่มีอิทธิพลต่อการเจริญเติบโตของข้าวโพดหวานที่ปลูกในดินลูกรังและดินทราย ในดินลูกรังพบว่าถ่านแกลบทำให้น้ำหนักแห้งของส่วนเหนือดินของข้าวโพด (2.77 กรัมต่อกระถาง) มากกว่าดินที่ไม่ได้รับสารปรับปรุงดิน (0.40 กรัมต่อกระถาง) และถ่านแกลบทำให้น้ำหนักแห้งของข้าวโพดไม่แตกต่างจากการใช้ปุ๋ยเคมี (3.41 กรัมต่อกระถาง) น้ำหนักแห้งของข้าวโพดที่ได้รับมูลวัว (1.14 กรัมต่อกระถาง) ไม่แตกต่างจากข้าวโพดที่ปลูกในดินที่ไม่ได้รับสารปรับปรุงดิน ในดินทรายพบว่าการใช้ปุ๋ยชนิดต่าง ๆ ร่วมกับถ่านแกลบทำให้น้ำหนักแห้งส่วนเหนือดินของข้าวโพดมากกว่าการใช้ปุ๋ยชนิดใดชนิดหนึ่งเพียงอย่างเดียว นั่นคือ การใช้ปุ๋ยเคมีร่วมกับถ่านแกลบทำให้ข้าวโพดมีน้ำหนักแห้ง 9.25 กรัมต่อกระถาง แต่การใช้ปุ๋ยเคมีอย่างเดียวทำให้ข้าวโพดมีน้ำหนักแห้ง 6.99 กรัมต่อกระถาง และการใช้มูลวัวร่วมกับถ่านแกลบทำให้ข้าวโพดมีน้ำหนักแห้ง 4.22 กรัมต่อกระถาง แต่การใช้มูลวัวเพียงอย่างเดียวทำให้ข้าวโพดมีน้ำหนักแห้ง 2.18 กรัมต่อกระถาง ส่วนในกรณีของปุ๋ยหมักในดินทรายไม่พบความแตกต่างระหว่างการใช้ปุ๋ยหมักร่วมกับถ่านแกลบ (4.32 กรัมต่อกระถาง) กับการใช้ปุ๋ยหมักเพียงอย่างเดียว (4.25 กรัมต่อกระถาง) กลไกการตอบสนองทั้งด้านลบและด้านบวกของพืชต่อถ่านแกลบและต่อปุ๋ยอินทรีย์และปุ๋ยเคมีได้อภิปรายเอาไว้ในบทความนี้ ในการวิจัยต่อไปควรมีการศึกษาการใช้ถ่านร่วมกับปุ๋ยเคมีในอัตราที่แตกต่างกันทั้งนี้เพื่อลดปริมาณการใช้ปุ๋ยเคมี

คำสำคัญ: ปุ๋ยเคมี ดินเนื้อหยาบและดินปนกรวด การเจริญเติบโตของข้าวโพด มูลวัว ถ่านแกลบ

Abstract

Rice husk charcoal (RHC) used as a soil amending material has potential to improve fertility of degraded tropical lateritic and sandy textured soils. Two greenhouse experiments were conducted to investigate effects of RHC and its combined application with other conventional fertilizers, including chemical fertilizer (CF), cow manure (CM), and compost (CP), on sweet corn growth in the lateritic and sandy soils. In the lateritic soil, RHC produced significantly higher corn shoot dry biomass (2.77 g pot-1) than unamended soil (0.40 g pot-1), while the RHC treatment produced comparable corn biomass to the CF (3.41 g pot-1). Shoot dry biomass of corn under CM (1.14 g pot-1) was not significantly different from that under unamended soil. Meanwhile in the sandy soil, fertilizers in combination with RHC brought about higher biomass than fertilizers applied alone, i.e., CF+RHC (9.25 g pot-1) vs CF alone (6.99 g pot-1); and CM+RHC (4.22 g pot-1) vs CM alone (2.18 g pot-1). Regarding CP, there was no significant difference in corn shoot dry biomass between CP+RHC (4.32 g pot-1) and CP alone (4.25 g pot-1) in the sandy soil. Mechanisms underlying plant negative and positive responses to RHC and the conventional organic and chemical fertilizers were discussed. The use of combination of charcoal with different rates of chemical fertilizer with the aim of lowering amount of chemical fertilizer used is to be further investigated.

Keywords: Chemical fertilizer, Coarse textured and skeleton soils, Corn growth, Cow manure, Rice husk charcoal

1. Introduction

Fertility improvement of degraded sandy and lateritic (skeleton) soils; major problem soils in Northeast Thailand [1], have been performed via application of various conventional fertilizers, e.g., chemical fertilizers, farmyard manure, and compost [2]. Although chemical fertilizers can rapidly promote plant growth and yields [3], their excessive amounts applied could bring about deleterious effects on soil fertility and the environment [4]. This was reported by Zhu et al. [4] that using excessive amounts of chemical fertilizers decreased soil fertility as shown by physical (e.g., increased hardness) and biological (e.g., biodiversity of microorganisms) indicators. Environmental degradation is seen in underground water and air contaminations through leaching of mineral nitrogen, ammonia volatilization, and greenhouse gas emission particularly nitrous oxide [4-6].

Organic fertilizers, such as animal and green manures and compost, have been promoted for their use to improve soil fertility and soil carbon sequestration [7]. Nevertheless, sole use of organic fertilizers does not meet the crop's nutrient requirement, since nutrients released from organic fertilizers do not synchronize with plant uptakes [8]. In addition, employing either chemical or organic fertilizers do not bring about the highest growth up to plants' genetic limits [9]. Combined uses of chemical and organic fertilizers with an organic fertilizer, such as charcoal, which has the potential to increase soil fertility, may bring about higher yield not achievable by using either chemical or organic fertilizer alone. Charcoal used as soil amendment, known as biochar, has been shown to increase soil fertility and plant growth [10] and decrease greenhouse gas emission [11]. In Northeast Thailand, charcoal is widely produced [12, 13], and rice husk derived charcoal is abundant due to large amount of rice production in this region. Recently, it was reported that rice husk charcoal could improve growth of certain crops, e.g., lentil (*Lens culinaris*) in an alkaline soil of Iraq [14], rice (*Oryza sativa*) in a paddy soil in Fukuoka, Japan [15]. Despite the research mentioned above on the application of rice husk charcoal to enhance soil fertility, to our knowledge, there is no published work on combined uses of rice husk charcoal with and without chemical and organic fertilizers in sandy and lateritic soils are still limited.

We have hypothesized that (i) rice husk charcoal would increase plant growth, and (ii) combined uses of rice husk charcoal with chemical and organic fertilizers bring about higher plant growth than sole uses of each of those fertilizers. The objectives of the current study were (i) to compare effects of rice husk charcoal with the conventional chemical and organic (cow manure) fertilizers on corn growth in a lateritic soil, and (ii) to determine effects of combined chemical and organic (cow manure and compost) fertilizers with rice husk charcoal on corn growth in a sandy textured soil.

2. Materials and methods

Two bioassays were conducted under greenhouse condition from December 2017 to January 2018. Average meteorological conditions during the experimental period were: mean temperature of greenhouse 31°C, dew point 15.6°C, relative humidity 64.3%, relative pressure 101.8 kPa and wind speed 2.88 km hr^{-1}

2.1 Soils

The Yang Talat series (isohyperthermic Typic Oxyaquic Kandiustults) represented the sandy textured soil while Sakon Nakhon series (Loamy-skeletal over fragmental mixed, isohyperthermic Petroferric Haplustults) was the lateritic soil. The Yang Talat soil was collected from 0 – 15 cm-depth at the Field Research Facilities of the Plant Science Section, Sakon Nakhon Rajabhat University (17° 11' 09.7" N; 104° 05' 18.8" E), while the Sakon Nakhon series (0 – 15 cm-depth) was collected from a paddy field in Kha-min subdistrict (17° 16' 41.8" N; 104° 00' 55.1" E). Both sites were located in Sakon Nakhon province, Thailand. Both soils were air-dried, ground to pass through a 2 mm-sieve for further use in the greenhouse experiments. Chemical properties of both soils are presented in Table 1.

2.2 Amending materials

Rice (*Oryza sativa*) husk charcoal was an agricultural by-product commercially available in agricultural product stores in Sakon Nakhon province. Cow manure was collected from a local free-range farm in Sakon Nakhon province. The manure was stored for one month before its use in the experiments. Compost was produced from raw materials including water hyacinth and cow manure. They were layered alternately and composted for about two months before their use in the experiment. These organic fertilizers were air-dried and screened to pass through a 2-mm sieve. The initial characteristics of these soil organic fertilizers are presented in Table 1.

Table 1 Initial properties of lateritic soil, cow manure, and rice husk charcoal

Property	Sandy soil	Lateritic soil	Cow manure	Compost	Rice husk charcoal
Proximate analysis					
Fixed carbon (%)	-	-	-	-	0.4
Volatile matter (%)	-	-	-	-	3.1
Ash (%)	-	-	-	-	96.5
pH	5.55	5.92	9.42	8.72	-
EC (mS cm^{-1})	0.013	0.013	5.35	4.29	-
Lime requirement (kg $CaCO_3$ rai^{-1})	296	511	-	-	-
Organic matter (g kg^{-1})	6.7	12.4	313	247	-
Total nitrogen (g kg^{-1})	0.092	0.94	16.4	17.3	-
NH_4^+ (mg kg^{-1})	3	18	18	18	-
NO_3^- (mg kg^{-1})	3	12	256	189	-
P (mg kg^{-1})	54	47	0.31	0.41	-
K (mg kg^{-1})	74	136	4.51	3.62	-
Ca (mg kg^{-1})	72	39	1.48	1.21	-
Mg (mg kg^{-1})	12	34	0.53	0.60	-
Fe (mg kg^{-1})	43	60	-	-	-

2.3 Experiment 1: Effects of rice husk charcoal, and conventional chemical and organic fertilizers on corn growth in a lateritic soil

This experiment was conducted to determine whether the plant positively responded to rice husk charcoal in comparison with the conventional fertilizers, i.e., chemical fertilizer and cow manure. A randomized complete block design with 4 treatments and 5 blocks was conducted. Four treatments included (i) unamended (negative control), (ii) chemical fertilizer (positive control and conventional chemical fertilizer), (iii) cow manure (conventional organic fertilizer), and (iv) rice husk charcoal. The recommended rate of chemical fertilizer (20 kg N rai^{-1} or 125 kg N ha^{-1}; 16 kg P_2O_5 rai^{-1} or 100 kg P_2O_5 ha^{-1}; 13.5 kg K_2O rai^{-1} or 84.4 kg K_2O ha^{-1}) for Ultisols issued by Thailand's Department of Agriculture (DOA) [16] were employed. As for the cow manure, the recommended rate (1.6 ton rai^{-1} or 10 ton ha^{-1}) following Chakraborty and Kundu [17] was used. The amount of rice husk charcoal used was 7.04 ton rai^{-1} (44 ton ha^{-1}) which was equal to 2% w/w, according to Butnan et al. [10]. Pots (17 cm diameter and 14.5 cm height) were filled with 3 kg air-died soil. Cow manure and rice husk charcoal were mixed thoroughly with the soils, watered to about 70 – 80 % water holding capacity, and incubated for 7 days before corn planting. The following chemical fertilizers were used as source of nutrients: 46-0-0 and 15-15-15. The amounts of the chemical fertilizers were calculated to provide the levels of nutrients specified in each treatment above. They were applied in solution form at corn planting time.

Corn was employed as the test plant. Six seeds of a commercial F1 hybrid sweet corn (*Zea mays*) were planted directly into each pot. Seedlings were thinned down to two plants per pot at 14 days after planting (DAP). Watering was done daily to about 70 -80% water holding capacity. Harvesting was done at 42 DAP, which was the seventh-leaf stage of corn growth and the nutrient requirement is very high. After shoot fresh weight was determined, the shoot samples were oven-dried at 65°C until constant weight.

2.4 Experiment 2: Effects of chemical fertilizer, cow manure, and compost in combination with rice husk charcoal on corn growth in a sandy soil

The second greenhouse experiment was conducted to investigate the effect of rice husk charcoal in combination with the conventional fertilizers, including chemical fertilizer, cow manure, and compost on plant growth in a sandy soil. A 3 × 2 factorial arrangement in randomized complete block design with 4 blocks was conducted. Two factors were evaluated; i.e., factor 1: fertilizer types including chemical fertilizer, cow manure, and compost; and factor 2: rice husk charcoal rates consisting of unamended and 2% w/w. Characteristics of fertilizers used and their application rates, as well as experimental management of experiment 2, were similar to those in experiment 1.

2.5 Laboratory analyses of soils, organic fertilizers, and rice husk charcoal

Proximate analysis of rice husk charcoal, including volatile matter, ash, and fixed carbon contents was done following ASTM D 7582 [18].

Soil pH was determined in a suspension of soil:H_2O ratio of 1:1, while that of organic fertilizers, i.e., cow manure and compost, was at a ratio of 1:10. The electrical conductivity of soils was in a suspension of soil:H_2O to 1:5, while that of organic fertilizers was 1:10. Lime requirement of soils was determined following the Woodruff method [19].

For both soils and organic fertilizers, organic matter content was determined by the wet digestion method of Walkley and Black [20], and available P was extracted by Bray2 solution (0.1 *M* HCl + 0.03 *M* NH_4F with pH 1.5) and determined colorimetrically by a spectrophotometer at the wavelength of 820 nm [21]. Extractable K, Ca, and Mg were extracted by 1 *M* NH_4OAc at pH 7.0, while Fe was extracted by diethylenetriaminepentaacetic acid (DTPA) solution, and these cations were determined by an atomic absorption spectrophotometer [22]. Total N was determined by the micro-Kjeldahl method [23], while mineral N, i.e., NH_4^+ and NO_3^-, were extracted with 2 *M* KCl and determined by the steam distillation method [24].

2.6 Data calculation and statistical analyses

Leaf area of a leaf of corn plant was calculated based on Montgomery [25] as follows: Leaf area (a single leaf) = leaf width × leaf length × 0.75 and leaf area per plant followed Mutisya and Geadelmann [26] as follows: Leaf area per plant = leaf width × leaf length × 0.66 × 5.03.

For experiment 1, one-way analysis of variance (ANOVA) under randomized complete block design (RCBD) was employed to determined effects of chemical fertilizer, cow manure, and RHC on corn growth. Meanwhile, for experiment 2, two-way ANOVA under RCBD was used to test effects of the fertilizer types, rice husk charcoal rate, and their interactions on corn growth. Mean comparisons were performed using Tukey's studentized range test. The statistical analyses were performed using Statistix 10 (Analytical Software, FL, USA). Significant differences were at $p \leq 0.05$.

3. Results

3.1 Experiment 1

In the lateritic Sakon Nakhon soil, corn shoot fresh (Figure 1a) and dry biomass (Figure 1c) were significantly higher in rice husk charcoal and chemical fertilizer treatments than the unamended treatment. Meanwhile, plant height (Figure 2a) and leaf area (Figure 3a) were significantly higher in the soil treated with rice husk charcoal and chemical fertilizer than those in the unamended soil mostly during 34 – 42 DAP. On the other hand, the above corn growth parameters under cow manure treatment were not significantly different from the unamended soil (Figures 1a, 1c, 2a, and 3a).

3.2 Experiment 2

There were significant interactions between fertilizer type factor and rice husk charcoal rate factor pertaining to fresh and dry shoot biomass, and height of corn plant in the sandy textured Yang Talat soil (Table 2).

The combined use of rice husk charcoal with chemical fertilizer and with cow manure resulted in significantly higher corn shoot biomass than sole use of these materials without the charcoal (Figures 1b and 1d). Corn height was significantly higher only in combined use of rice husk charcoal with cow manure than the sole use of cow manure at 16, 18, 26, and 30 – 42 DAP (Figure 2b). Significantly higher leaf area of the combined use of rice husk charcoal with chemical fertilizer than the sole use of chemical fertilizer was found at 38 DAP (Figure 3b). Meanwhile, significantly higher leaf area under combined use of rice husk charcoal with cow manure than the sole use of cow manure was observed at 14, 18-22, and 26 DAP. Nevertheless, shoot biomass, height, and leaf area of corn under the compost treatments with as compared to without charcoal were not significantly different.

Cow manure alone treatment produced the lowest corn growth as seen in all growth parameters, including shoot biomass, plant height and leaf area (Figures 1b, 1d, 2b, and 3b).

4. Discussion

4.1 Rice husk charcoal produced comparable improvement in corn growth to chemical fertilizer in a lateritic soil

Rice husk charcoal could improve corn growth relative to the unamended soil at a comparable level to chemical fertilizer at the DOA recommended rate (Figure 1a, c, 2a, 3a). These results corroborated those of Abrishamkesh et al. [14] and Pratiwi and Shinogi [15], who found increased growth of lentil and rice plants, respectively, after application of rice husk charcoal. An increase in corn growth under rice husk charcoal was likely due to high ash content of the charcoal (Table 1). Ash contains a number of plant nutrients, such as P, K, Ca, and Mg [10]. High ash could result in increased soil pH of the studied acid lateritic soil due to the presence of metal oxides, such as CaO, K_2O, MgO, and SiO_2 [11], which could increase availability of some plant nutrients [10] in this soil. Additionally, charcoal has been reported to add N to soils by increasing abundance, diversity, and activity of free-living N_2-fixing bacteria [27]. Moreover, charcoal may reduce N losses through a number of mechanisms. Clough et al. [28] reviewed mechanisms underlying charcoal's capacity to decrease N losses including: (i) decreasing NH_3 volatilization and N gas (N_2O and N_2) emissions through adsorption of NH_4^+ and NO_3^- in soil solution onto charcoal surface or trapping them in charcoal pores, (ii) providing conditions conducive to occurrence of N forms that are more resistant to losses such as NH_4^+ form, through inhibiting nitrification, and organic N form in microbial biomass, through promoting N immobilization.

Furthermore, increased soil pH by charcoal could have alleviated the deleterious effect of Al and Fe which are commonly found in tropical Ultisols [10].

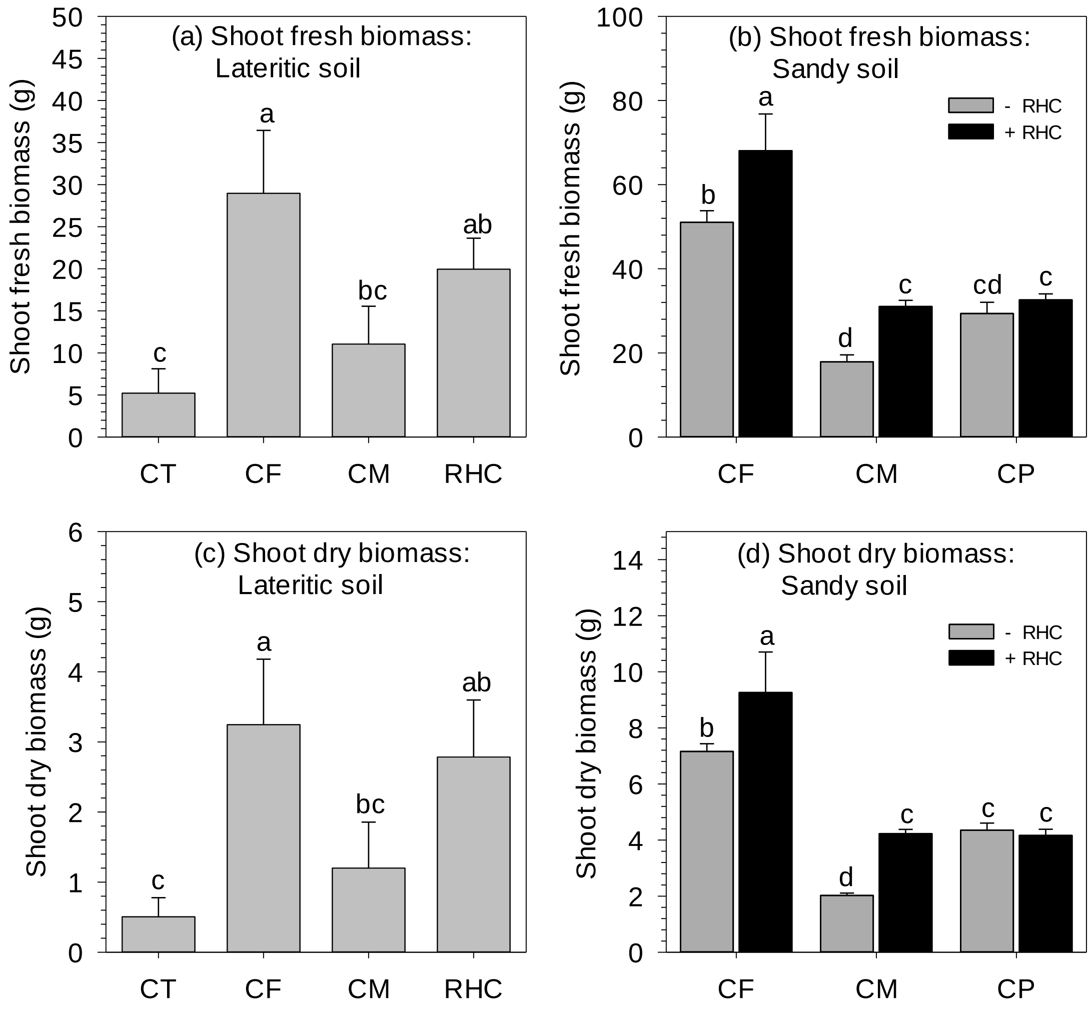
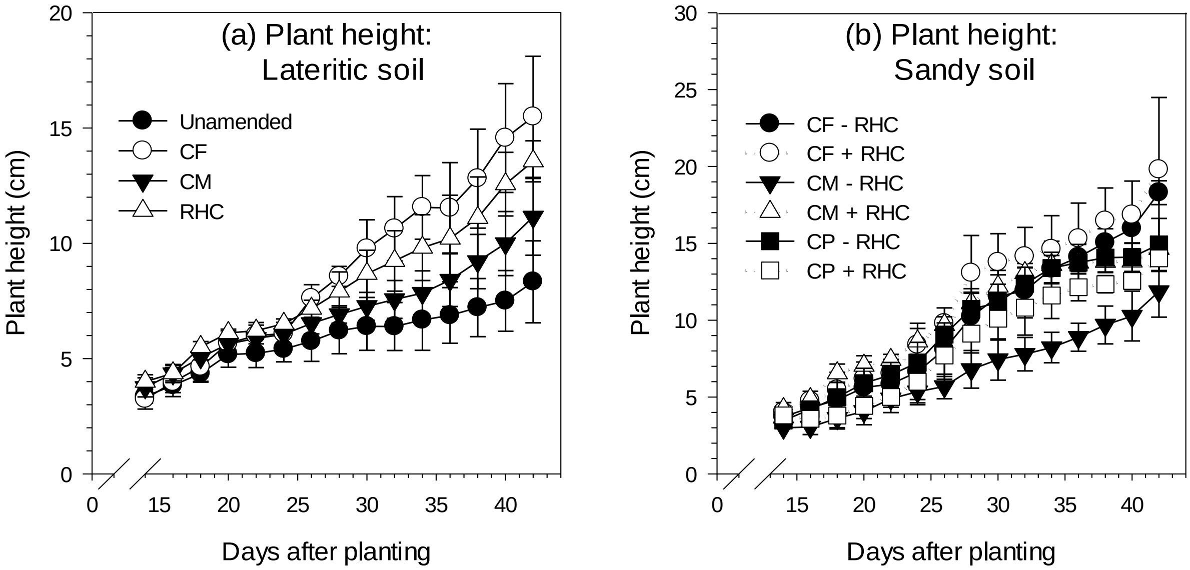


Figure 1 Effects of different soil amending materials including unamended (control, CT), chemical fertilizer (CF), cow manure (CM), and rice husk charcoal (RHC) on: (a) shoot fresh biomass, and (c) shoot dry biomass of corn in the lateritic Sakon Nakhon soil series; and effects of CF, CM, and compost (CP) in combination applications without (-RHC) and with (+RHC) rice husk charcoal on: (b) shoot fresh biomass, and (d) shoot dry biomass of corn in the sandy textured Yang Talat soil series. Bars with the same letters of either fresh or dry biomass are not statistically different ($p \leq 0.05$; Tukey's Studentized Range Test). Error bars represent standard deviation.



Amendment	Days after planting														
	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
Unamended	b	ns	b	ns	ns	ns	b	c	b	b	c	c	c	c	c
CF	b	ns	ab	ns	ns	ns	a	a	a	a	a	a	a	a	a
CM	a	ns	ab	ns	ns	ns	ab	bc	b	b	bc	bc	bc	bc	bc
RHC	a	ns	a	ns	ns	ns	ab	ab	ab	ab	ab	ab	ab	ab	ab

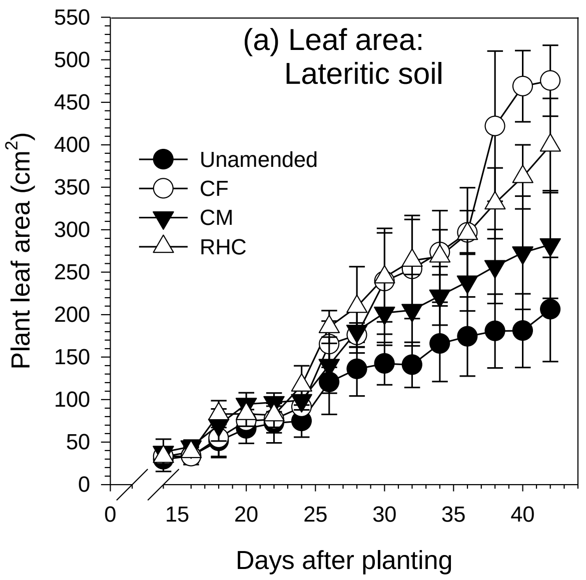
Amendment	Days after planting														
	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
CF - RHC	ns	ab	ab	ns	ns	ns	ab	ab	ab	a	ab	ab	ab	ab	ab
CF + RHC	ns	ab	ab	ns	ns	ns	a	a	a	a	a	a	a	a	a
CM - RHC	ns	b	b	ns	ns	ns	b	b	b	b	c	c	c	d	c
CM + RHC	ns	a	a	ns	ns	ns	a	ab	a	a	ab	ab	b	bc	bc
CP - RHC	ns	ab	ab	ns	ns	ns	a	ab	ab	a	ab	ab	b	bc	bc
CP + RHC	ns	ab	ab	ns	ns	ns	ab	ab	ab	ab	b	b	b	c	bc

Figure 2 Effects of different soil amending materials including unamended (control, CT), chemical fertilizer (CF), cow manure (CM), rice husk charcoal (RHC) on (a) corn height in the lateritic Sakon Nakhon soil series; and effects of CF, CM, and compost (CP) in combination applications without (-RHC) and with (+RHC) rice husk charcoal on (b) corn height in the sandy textured Yang Talat soil series. The inset tables demonstrate mean comparisons among treatments within a soil and a time interval. Similar letters within a time interval are not significantly different ($p \leq 0.05$, Tukey's studentized range test). Vertical bars represent standard deviation.

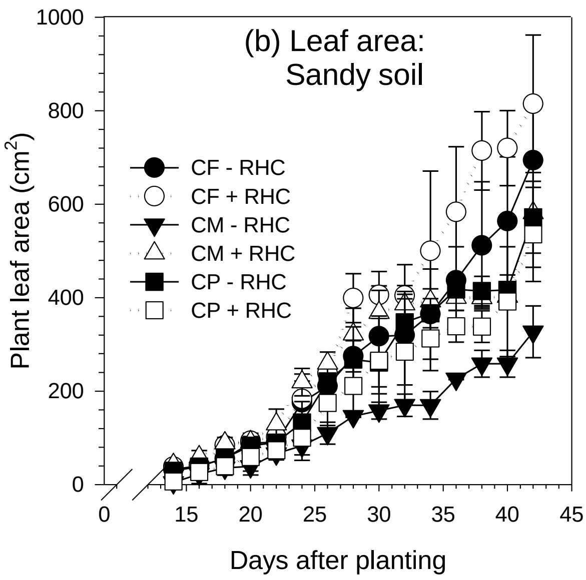
4.2 Cow manure at the recommended rate had low potential to improve plant growth in lateritic and sandy textured soils

The recommended rate of cow manure had low potential to improve corn growth in the studied tropical soils as seen in no significant improvement in corn growth under cow manure relative to the unamended in the lateritic soil (Figure 1a, 1c, 2a, and 3a), and in the lowest corn growth in the sandy textured soil compared to chemical fertilizer and compost (Figure 1b, 1d, 2b, and 3b). These results were rather surprising and inconsistent with previous findings that cow manure increased growth of corn in the coarse-textured Yasothon soil [29], and a medium textured dark loessial soil [30]. Cattle manure was also reported to increase growth of Chinese kale in the fine-textured Ratchaburi and coarse-texture Roi Et soils [31].

The low corn growth under the cow manure treatment found in this study is most likely due to lower application rates of cow manure than the previously published works. The application rate of cow manure employed in this study followed a worldwide recommended rate of 10 t ha^{-1} [17]. This rate was much lower than those used in other research works; for example, 15.6 t ha^{-1} in Seripong and Vityakon [29], 20 t ha^{-1} in Vityakon et al. [31], 15 t ha^{-1} in Wang et al. [30], and 360 t ha^{-1} in Shakoor et al. [32]. Even though a large number of studies revealed excellent positive impact of cow manure on plant growth, large quantities of the manure required to achieve satisfactory plant growth even at the recommended rate (10 t ha^{-1}) are prohibitive for small farmers who do not have cattle farming. The combined use of cow manure with a potential soil amendment, e.g., charcoal, for enhancing the manure's benefits and minimizing its application quantity is recommended.



Amendment	Days after planting														
	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
Unamended	ns	ns	ns	c	b	b	ns	b	b	b	b	b	b	c	b
CF	ns	ns	ns	bc	ab	ab	ns	ab	a	a	a	a	a	a	a
CM	ns	ns	ns	a	a	ab	ns	ab	ab	ab	ab	ab	b	bc	b
RHC	ns	ns	ns	ab	ab	a	ns	a	ab	ab	a	a	ab	ab	a



Amendment	Days after planting														
	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
CF - RHC	a-c	ns	a-c	ab	ab	ns	ab	ab	ab	ab	ab	ab	b	ab	ab
CF + RHC	ab	ns	ab	a	ab	ns	ab	a	a	a	a	a	a	a	a
CM - RHC	c	ns	c	b	b	ns	c	b	b	b	b	b	c	c	c
CM + RHC	a	ns	a	a	a	ns	a	ab	ab	ab	ab	ab	bc	bc	bc
CP - RHC	a-c	ns	a-c	ab	ab	ns	ab	ab	ab	ab	ab	ab	bc	bc	b
CP + RHC	bc	ns	bc	ab	b	ns	bc	b	ab	ab	ab	ab	bc	bc	bc

Figure 3 Effects of different soil amending materials including unamended (control, CT), chemical fertilizer (CF), cow manure (CM), rice husk charcoal (RHC) on (a) leaf area per corn plant in the lateritic Sakon Nakhon soil series; and effects of CF, CM, and compost (CP) in combination applications without (-RHC) and with (+RHC) rice husk charcoal on (b) leaf area per corn plant in the sandy textured Yang Talat soil series. The inset tables demonstrate mean comparisons among treatments within a soil and a time interval. Similar letters within a time interval are not significantly different ($p \leq 0.05$, Tukey's studentized range test). Vertical bars represent standard deviation.

Table 2 Analysis of variance (ANOVA) showing the effects of treatments on corn growth: Experiment 1, effects of different soil amending materials on corn growth in the lateritic Sakon Nakhon soil series; and Experiment 2, effects of fertilizer type factor and rice husk charcoal rate factor on corn growth in the sandy textured Yang Talat soil series.

Source of variance	df	*p*-value			
		Fresh biomass	Dry biomass	Height †	Leaf area ‡
Experiment 1					
Amending material	3	***	***	***	***
Experiment 2					
Fertilizer type (FT)	2	***	***	***	***
Rice husk charcoal rate (RHC)	1	***	***	**	**
FT x RHC	2	*	**	***	ns

*$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$; and ns = not significantly different (F-test)

† Height of corn plant in the final sampling date (42 days after planting)

‡ Leaf area per corn plant in the final sampling date (42 days after planting)

4.3 Rice husk charcoal enhanced corn growth in combination with chemical fertilizer and cow manure but not with compost in a sandy textured soil

Enhancement of corn growth by applications of chemical fertilizer and cow manure in combination with rice husk charcoal could be due to the charcoal beneficial roles in increasing plant nutrient availability, and alleviating some toxic elements present the tropical acid soils.

The non-responsive corn growth to the combined use of charcoal with compost relative to the use of sole compost could be due to some inherent detrimental effects of rice husk charcoal. Charcoal contains metal oxides that interact negatively with chelating agents produced by decomposing compost. Decomposing compost produced chelating agents, e.g., citric, and aspartic, acetic, lactic, butyric, propionic, valeric, isobutyric, and isovaleric acids, which promoted plant nutrient uptakes [33, 34]. Metal oxides of this high-ash-content rice husk charcoal may have deactivated the chelates. Wang et al. [35] reported that calcite, an ash component, could precipitate organic compounds such as citrate through ligand exchange process. Increased soil pH due to ash component of rice husk charcoal may deactivate beneficial enzymes produced in composting process. Jindo et al. [36] demonstrated that OH^- radical from charcoal ash deactivated β-glucosidase, *p*-nitrophenyl phosphatase, and acid phosphatase in soils.

Fixed carbon component of rice husk charcoal could also decrease the activity of these composting derived enzymes via the ligand exchange process [36]. Additionally, Fang et al. [37] and Joseph et al. [38] suggested that fixed carbon could adsorb organic acids and rendered them non-functional.

5. Conclusions

The results showed clearly that rice husk charcoal in the short term improved sweet corn growth in the lateritic soil comparable with the recommended rate of chemical fertilizer. However, in sandy soils, to enhance effective uses of conventional chemical and organic fertilizers, combined uses of rice husk charcoal with chemical fertilizer and cow manure obviously increased sweet corn growth.

As differ from chemical fertilizer and cow manure, the combination of rice husk charcoal with compost did not enhance sweet corn growth. Ash component of this high ash charcoal was identified as a likely negative factor masking the beneficial effects of compounds, especially organic acids and decomposition enzymes, produced in the composting process. Precipitation of compost-derived organic compounds by metal oxides in ash and deactivation of beneficial enzymes due to increased soil pH were proposed as dominant mechanisms underlying the negative effects of rice husk charcoal.

The sole use of the recommended rate of cow manure demonstrated clearly to have a low capacity to improve sweet corn growth in both the lateritic and sandy textured soils.

Combining charcoals with chemical fertilizer (at lower than the recommended rate of the latter) in order to lower the amount of the chemical fertilizer used is to be further investigated

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