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Research Paper

The response of sweet corn to biochar and chemical fertilizer applications for a sandy soil

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A*bstract.* Sandy soils have limited agricultural production. Farmers try to overcome sandy soil constraints by using various soil amendments. This study aims to evaluate the combined effects of biochar and chemical fertilizer on plant growth and nutrient uptake for sweet corn grown on a sandy soil in a glasshouse experiment. The pot experiment was conducted in a glasshouse at the Land Development Department, Bangkok using a super agro sweet corn variety (Market's variety) (open pollinated variety) (*Zea mays* L.) on an Ustic Quartzipsamment at field capacity. The Complete Block Design with 2 replications and 16 treatments included 2 controls, 14 different biochar treatments (eucalyptus wood and rice husk biochars) with and without chemical (N, P and K) fertilizers applied at 1 and 2 times the fertilizer recommendation. The results showed that treatment 16 (rice husk biochar 40 ton ha^{-1} with chemical fertilizer at 2 times fertilizer recommendation: R40F2) was the best treatment which significantly ($p<0.05$) increased sweet corn growth and nutrient uptake. Clearly, biochar can increase nutrient uptake and plant yield to the benefit of farmers however biochar does not have sufficient plant nutrient contents to support maximum plant growth. Applying biochar together with chemical fertilizers is the best solution for sandy soils.

Key words: Sweet corn, rice husk biochar, eucalyptus wood biochar, chemical fertilizer, sandy soil.

INTRODUCTION

The limiting factors for agricultural use of sandy soils include nutrient deficiencies, acidity, low organic matter content and low water holding capacity. To overcome these constraints, farmers need to add diverse inputs. When soil cannot supply all essential plant nutrients to support plant growth, farmers usually apply high quantities of chemical fertilizers. Chemical fertilizer application is one of the most effective inputs to increase nutrient uptake by crop plants and enhance yields (Sultana *et al*., 2015). Fertilizer prices represent a large portion of a producer's capital. It is very important to maximize fertilizer use efficiency; therefore, chemical fertilizer application is based on soil testing and "tailor-made fertilizers" or precise application rates. Rice is the most important economic crop and it is the primary staple crop in the country. Over 50% of the Thai farmland is devoted to rice with about 20 million tons of rice produced annually.

Table 1. Latitude and longitude and physical properties of top soil (Ap horizon, 0-15 cm depth) from Khonkhen province, Northeastern Thailand.

Latitude	Longitude	Sand	Silt	Clay	Texture	Water retention (% by weight)		Bulk density (g cm^{-3})
			%			FC 1/3 atm	PWP 15 atm	
16.4697N	102.8458E	83	12	5	Loamy sand	3.7	1.3	1.49

Eucalyptus has been extensively planted in Thailand. The total area of eucalyptus growth is approximately 400 000 ha. The annual planting rate of Eucalyptus has increased gradually over the last decade in response to the high demand for wood, especially chips and poles, for both domestic consumption and export. Eucalyptus plantation practices include pruning some branches which creates abundant wastes. Thai farmers in northeastern part of Thailand have paddy fields or maize with eucalyptus plantings on ridges. Based on these types of land use, rice husk and eucalyptus branches are predominant agricultural wastes in the region. Biochar production can utilize these waste materials (Lehmann and Joseph, 2015).

Biochar is a carbon-rich material produced by heating biomass in the absence of oxygen. Biochar can persist in soils for years and can enhance carbon sequestration for a long period (Downie *et al*., 2011). Biochar added to soil can enhance crop growth, increase water and nutrient retention as well as increase soil carbon sequestration (Ahmed *et al.*, 2016). The properties of biochars depend on feedstock and pyrolysis temperature (Zhao *et al*., 2013; Tag *et al*., 2016). Biochar obtained from rice wastes have unique chemical properties because of the incorporation of silica into its structure (Prakongkep *et al*., 2013) whereas, biochar produced from woody materials contains little Si and has a higher carbon content. All biochars contain plant nutrient elements (Jindo *et al.*, 2014; Prakongkep *et al.*, 2015).

The use of biochar as a soil amendment is not an innovative concept. The effect of biochar addition on crop yield is more pronounced for infertile soils compared to fertile soils (El-Naggar *et al*., 2019). Moreover, the effect of biochar on crop yield and plant nutrition is variable, and it is not always effective with supplementation with mineral fertilizers sometimes being necessary to promote crop growth (Chan *et al*., 2008; Alburquerque *et al*., 2013). Positive effects on crops due to the addition of biochar combined with chemical fertilization have been reported (Blackwell *et al.*, 2015; Inal *et al.*, 2015) however biochar application alone may improve soil quality and increase maize yields (Manolikaki and Diamadopoulos, 2019).

This study was conducted to assess the combined effect of biochar and chemical fertilizer on acidic sandy soils for sweet corn growth. Sweet corn was selected as the crop as it is one of the most popular crops in the tropics and it exhibits a marked response to fertilizer treatment (Kaizzi *et al*., 2012).

MATERIALS AND METHODS

Properties of soils

A sandy soil was taken from 0-15 cm depth from an agricultural field near the Land Development Regional Office 5, Khon Kaen province, Northeastern, Thailand (Longitude 102.8458E and Latitude 16.4697N). The loamy sand was classified as Ustic Quartzipsamment (Soil Survey Staff, 2014a). The soil was air-dried, sieved to pass through 2 mm mesh, thoroughly mixed and stored in polythene bags at room temperature. It was used for standard chemical and physical analysis (Soil Survey Staff, 2014b) and the pot experiment. Core samples taken in the field were used for bulk density measurement. Soil properties are presented in Tables 1 and 2.

Biochar production and characterization

Biochars were obtained by carbonization at 300-350^{o}C of eucalyptus wood and rice husks. Biochars were crushed to a uniform particle size then passed through 2 mm sieve prior to experimental use. Biochar morphology was observed by scanning electron microscopy (SEM, JEOL6400) of the biochar fracture surfaces. The pH and EC of the biochar were measured in a 1:10 (biochar: distilled water) extract. For ash content, biochars were burned in a furnace at 600^{o}C for 6 hrs. For total element determination, biochar ashes were digested with aqua regia [1:3 hydrochloric acid (HCl): nitric acid (HNO_3)] and for water soluble elements, biochars were extracted with distilled water [0.5 g: 100 mL] shaking overnight. Both

Table 2. Chemical properties of top soil (Ap horizon, 0-15 cm depth) from Khonkhen province, Northeastern Thailand.

pH 1:1	EC1:5 (dS cm^{-1})	OM	Total N	CEC	Exchangeable cations				Avail. P
					Ca	K	Mg	Na	mgP kg^{-1}
		(%)		(cmol kg^{-1})	(cmolkg^{-1})				
5.9	0.08	0.17	0.10	1.2	0.24	0.24	0.07	0.47	90

Table 3. Detailed treatment combination used for pot experiment.

Treatment	Soil amendment	Chemical fertilizer*	Abbreviation
1	Control	-	C01
2	Control	-	C02
3	-	recommendation rate	F1
4	-	2 times recommendation rate	F2
5	Eucalyptus wood biochar 10 t ha^{-1}	-	E10
6	Eucalyptus wood biochar 40 t ha^{-1}	-	E40
7	Rice husk biochar 10 t ha^{-1}	-	R10
8	Rice husk biochar 40 t ha^{-1}	-	R40
9	Eucalyptus wood biochar 10 t ha^{-1}	recommendation rate	E10F1
10	Eucalyptus wood biochar 10 t ha^{-1}	2 times recommendation rate	E10F2
11	Eucalyptus wood biochar 40 t ha^{-1}	recommendation rate	E40F1
12	Eucalyptus wood biochar 40 t ha^{-1}	2 times recommendation rate	E40F2
13	Rice husk biochar 10 t ha^{-1}	recommendation rate	R10F1
14	Rice husk biochar 10 t ha^{-1}	2 times recommendation rate	R10F2
15	Rice husk biochar 40 t ha^{-1}	recommendation rate	R40F1
16	Rice husk biochar 40 t ha^{-1}	2 times recommendation rate	R40F2

* Chemical fertilizer application rate was based on soil testing; Urea (46-0-0), triple superphosphate (TSP) (P_2O_5; 0-46-0), potassium chloride (muriate of potash) (KCl; 0-0-60) were used at the rate of 188-30-30 kg ha^{-1} (83-14-14 mg pot^{-1}) (recommendation rate of chemical fertilizer) and 376-60-60 kg ha^{-1} (166-28-28 mg pot^{-1}) (2 times the recommendation rate of chemical fertilizer), respectively (Department of Agriculture 2010).

Table 4. Ash, pH and EC of biochars.

Biochar	Ash (%)	pH1:5	EC1:5 (dS m^{-1})
Eucalyptus wood	36	7.6	0.10
Rice husk	38	7.7	0.70

Table 5. Total elements, water soluble and proportion of water soluble of biochar (mg kg^{-1})

Biochar	Si	Al	Ca	Cu	Fe	K	Mn	Mg	Na	Ni	P	Pb	Zn
Eucalyptus wood													
Total element	2,500	420	3,239	10	731	386	68	292	661	6	106	5	6
Water soluble	nd	4.6	336	0.2	0.5	90	0.6	35	318	nd	nd	0.5	nd
Proportion	nd	0.01	0.10	0.02	0.001	0.20	0.009	0.12	0.48	nd	nd	0.10	nd
Rice husk													
Total element	194,000	199	1,771	7.0	496	7,761	282	810	250	3	835	3.0	28
Water soluble	nd	8.3	287	1.1	7.6	4,848	24.9	183	154	0.1	434	0.1	0.5
Proportion	nd	0.04	0.16	0.16	0.02	0.60	0.09	0.23	0.62	0.03	0.50	0.03	0.02

nd = non detectable

extracts were analyzed by ICP-OES.

Experimental site

The experiment was conducted in a glasshouse at the Office of Science for Land Development, Bangkok, Thailand (Elevation 20 m.s.l, Longitude 100.57094E and Latitude 13.83768N), during the period from September to October 2018. The average temperature was 29.0ºC.

Plant material

Super Agro sweet corn (open pollinated variety) (*Zea mays* L.) was used for this pot experiment.

Experimental design and treatments

The experimental design used was a completely randomized design (CRD) with two replications. Biochar and/or chemical fertilizers were mixed with 2 kg soil to prepare the substrates for sweet corn growth. The test treatments were shown in Table 3.

Cultural practices

Four sweet corn seeds were placed at 1 cm depth into 8 inch diameter plastic pots, containing about 2 kg of loamy sandy soil (sand 83%, silt 12% and clay 5%). Five days after seedling emergence the seedlings were thinned to two per pot. The moisture content in all pots was maintained at field capacity and irrigated with DI water. All pots were randomized every morning to avoid differences in sunlight. Fungicide (Captan 2 g: 1000 mL water) solution was applied every seven days. The experiment was terminated 30 days after seeding. A harvest of the above ground (stalks and leaves) biomass took place at the end of the experiment. The plant material was dried at 60ºC until a constant weight was reached and then ground. The soil in each pot was thoroughly mixed. Soil samples were collected from each pot

Table 6. Duncan's Multiple Range Test (DMRT) (α = 0.05) of mean pH, EC, available K and available P of soil at 30 days after sweet corn planting (Pot experiment).

Treatment		pH1:1H_2O	EC1:5H_2O (μs cm^{-3})	Avail K (mg kg^{-1})	Avail P (mg kg^{-1})
1	C1	5.27f	29.1c-f	21.6e	0.99cde
2	C2	5.32def	23.2ef	22.6de	0.56e
3	F1	5.28ef	47.3b-e	26.3de	0.75de
4	F2	5.31def	84.6a	34.1cde	1.41bc
5	E10	5.32def	22.4f	23.7de	0.44e
6	E40	5.44a-d	28.3def	27.4de	0.53e
7	R10	5.12g	26.1ef	35.1cd	0.69de
8	R40	5.49ab	37.6b-f	88.5a	1.93ab
9	E10F1	5.23fg	40.7b-f	29.3cde	0.57e
10	E10F2	5.31def	55.6b	25.7de	1.28cd
11	E40F1	5.55a	39.8b-f	32.1cde	0.72de
12	E40F2	5.47abc	57.4b	28.0de	1.02cde
13	R10F1	5.35c-f	47.3b-e	41.0c	0.91cde
14	R10F2	5.41b-e	51.4bcd	34.5cd	1.25cd
15	R40F1	5.52ab	46.2b-f	63.3b	1.45bc
16	R40F2	5.52ab	53.0bc	66.7b	2.37a
	CV%	2	40	51	54

Means in each column followed by different letter (s) are significantly different at the 0.05 probability level

at the end of the experiment for chemical analysis.

Plant analysis

A combination of nitric-perchloric acids HNO_3–$HClO_4$ in a ratio 2:1 was used for plant digestion. Uptake of nutrients by plants was calculated by multiplying nutrient concentration with the dry matter weight.

Statistical analysis

One-way ANOVA was performed with the Excel Microsoft Office professional Plus 2010 to compare the means of nutrients concentration, plant height and dry weight of aboveground (stalks and leaves) and soil properties. The treatments comparison was made with the Duncan (Post-hoc) test at p<0.05 level of significant using Statistica software (version 8.0) (Statsoft Inc., 2007).

RESULTS AND DISCUSSION

The soil reaction was rated as moderately acid (pH 5.9) (Table 2). Analysis of the experimental soil before planting revealed that it was very low in organic matter, low in total N, and medium in K content and high in available P (Table 2). These results were used to calculate chemical fertilizer recommendations for the pot experiment. Eucalyptus wood and rice husk biochars are slightly alkaline (pH 7.6 to 7.7) with a high ash content (36 to 38%) and low EC (0.1 to 0.7 μs cm^{-1}) (Table 4). Total element, water soluble element and the proportion of water soluble elements in the biochars used in our experiment are shown in Table 5. Effects of biochar on soil properties are shown in Table 6, application of rice husk and eucalyptus biochars (40 ton ha^{-1}) with/without

Table 7. Duncan's Multiple Range Test (DMRT) (α = 0.05) of mean height, dry weight and element uptake of aboveground (stalks and leaves) at 30 days after sweet corn planting (Pot experiment).

Treatment	Height (cm)	Dry weight (g)	Si	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
			(g pot^{-1})							(μg pot^{-1})			
1.C1	24.9abc	1.29ef	0.22j	1.94e	0.18g	3.10gh	0.49de	0.43fg	0.095c	92e-h	167gh	42e	4.86d-g
2.C2	25.1abc	1.19ef	0.30ij	1.38e	0.14g	2.39h	0.42de	0.35g	0.085c	81fgh	227fgh	55de	3.58g
3.F1	18.3c	1.38ef	2.00d-g	5.19d	0.27fg	3.59gh	0.81b-e	0.63de	0.103c	151def	461c-g	82cde	4.83d-g
4.F2	22.3bc	1.86de	3.62bc	8.39c	0.48ce	5.48d-g	1.07abc	0.79cde	0.065c	162de	565cde	155ab	8.38cd
5.E10	24.5abc	1.03f	0.51hij	1.35e	0.17g	2.46h	0.26e	0.30g	0.070c	65gh	157h	52de	3.57fg
6.E40	25.3abc	0.86f	0.56g-j	1.25e	0.15g	2.28h	0.30e	0.30g	0.026c	54h	162h	36e	2.91g
7.R10	29.3ab	1.40ef	0.71f-j	1.33e	0.19g	4.60e-h	0.39de	0.32g	0.055c	84fgh	320e-h	55de	4.20efg
8.R40	29.5ab	2.22d	2.04def	2.20e	0.61cd	9.24bc	0.41de	0.25g	0.132c	136d-g	287e-h	72de	4.43efg
9.E10F1	18.0c	1.93de	1.93d-h	6.40d	0.39ef	4.09fgh	0.93a-d	0.91bc	0.134c	167d	650bcd	108b-e	7.70cde
10.E10F2	23.3bc	3.42c	3.22bcd	10.81ab	0.65bd	6.71de	1.44a	1.06b	0.182bc	275bc	716abc	154ab	12.03ab
11.E40F1	23.8abc	1.80de	1.71e-h	5.32d	0.35ef	3.26gh	0.75cde	0.64de	0.033c	135d-g	337e-h	114bcd	7.18c-f
12.E40F2	23.5bc	2.34d	2.30cde	9.47bc	0.61d	7.21cd	1.38a	0.97bc	0.094c	182d	397d-h	210a	10.54abc
13.R10F1	26.1ab	2.29d	1.49e-i	6.01d	0.47e	6.53def	0.62cde	0.60ef	0.091c	174d	472c-f	150abc	8.06cd
14.R10F2	27.0ab	3.74bc	5.42a	9.77abc	0.76b	9.75b	1.31ab	1.25a	0.149c	251c	946a	197a	13.13a
15.R40F1	25.3abc	4.35b	4.48ab	8.96bc	0.76b	16.65a	1.07abc	0.80cd	0.392a	330b	684a-d	149abc	8.69bc
16.R40F2	31.0a	5.29a	4.60ab	11.58a	1.17a	16.42a	1.47a	0.97bc	0.310ab	405a	879ab	166ab	12.83a
CV %	17	56	76	66	63	70	55	48	85	58	57	54	49

Means in each column followed by different letter (s) are significantly different at the 0.05 probability level

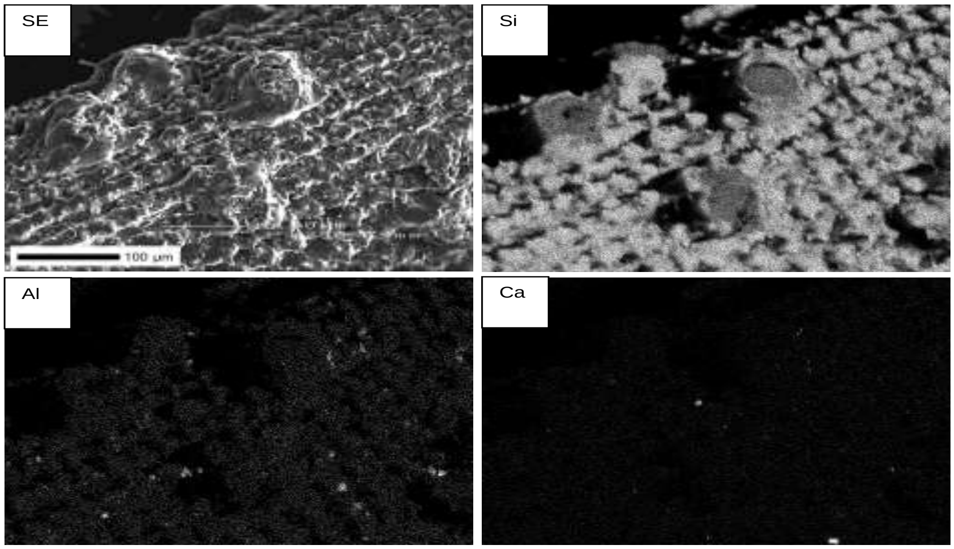

Figure 1. Secondary electron scanning micrographs (SE) and element maps of rice husk biochar showing silica compounds.

chemical fertilizer (E40, R40, E40F1, E40F2, R40F1 and R40F2 significantly increased soil pH. The higher recommendation rate (F2) of fertilizer raised EC moderately. Rice husk biochar (40 ton ha^{-1}) with/without chemical fertilizer (R40, R40F1 and R40F2) increased available K and P in soil.

The effect of biochar on plant growth and nutrient uptake is shown in Table 7. The results show that the growth of sweet corn was affected by biochar additions at high rate of application (40 ton ha^{-1}). Maximum height of sweet corn plants (average height 31 cm) was with the application of R40F2. Plant dry weight was significantly affected by experimental treatments (Table 7). The dry weight of sweet corn plants obtained after 30 days of growth indicated that R40F2 was the most efficient treatment. Significant ($P<0.05$) differences in nutrient uptake by plants were observed due to the use of different amendments (Table 7). Silicon uptake for R10F2, R40F1 and R40F2 were higher than for other and control treatments. Sweet corn fertilized with rice husk biochar at twice the recommended rate of chemical fertilizer (R40F2) produced the highest N, P, K Ca, S, Fe, Mn, Zn and Cu uptakes.

Generally, biochar has a liming effect on acidic soil pH (Dume *et al*., 2015) as observed here. Some studies have found biochar to be most effective when it is applied with mineral fertilizers (Chan *et al*., 2008; Atkinson *et al*., 2010; Van Zwieten *et al*., 2010; Alburquerque *et al*., 2013; Li and Shangguan, 2018) as is indicated by this study. Sweet corn height, dry weight and nutrient uptake were markedly affected by experimental treatments (Table 7). Biochar applications at higher levels affected sweet corn growth and nutrient uptake. The highest aboveground (stalks and leaves) nutrient uptake was for plants treated with rice husk biochar for two times the recommended rate of chemical fertilizer (R40F2). Control plants, chemical fertilizer only, biochar application without chemical fertilizer did not show significantly differences in plant properties however, the positive effects on crop growth due to the addition of biochar combined with chemical fertilization are evident.

Comparing eucalyptus wood biochar and rice husk biochar, improvements in sweet corn growth and nutrient uptake due to rice husk biochar were better than for eucalyptus wood biochar because total and available forms of plant nutrient elements such as K and P in rice husk biochar are higher than for eucalyptus wood biochar. Moreover, rice husk biochar has a high silica content (Figure 1) which is present as amorphous forms of silica resembling cristobalite and tridymite (Prakongkep *et al.*, 2013). Amorphous and crystalline forms of silica in rice husk biochar partly dissolve in soil solution and probably play an important role for sweet corn growth. Silicon reduces biotic stresses and abiotic stresses including climate stress, water deficiency stress, and mineral stresses (Guntzer *et al*., 2012). Silicon enhanced uptake of major essential elements and water and maintained physiological processes such as photosynthesis by plants exposed to a water deficit (Gao *et al.*, 2005; Eneji *et al.*, 2008; Gong *et al.*, 2008). The present data support this interpretation.

CONCLUSION

Biochars were produced from eucalyptus wood and rice husk by carbonization at 300 to 350°C. Sweet corn was grown for 30 days after seedling emergence in a glasshouse pot trial in a sandy soil (loamy sand: Ustic Quartzipsamment) amended with biochars at 10 and 40 ton ha^{-1} with/ without chemical fertilizer. The addition of R40F2 resulted in the highest increase of aboveground dry weight (5.29 g pot^{-1}) compared to the control (1.19-1.29 g pot^{-1}). Biochar alone is not sufficient to maximize crop production; therefore, additional mineral fertilizers must be applied. Rice husk biochar increased sweet corn growth more than eucalyptus wood biochar because rice husk biochar has a high content of silicon and potassium.

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