RICE-DERIVED BIOCHARS ENHANCE THE YIELD OF SPRING ONION (*ALLIUM CEPA* L. VAR. *AGGREGATUM*), WHILE REDUCING PESTICIDE CONTAMINATION IN SOIL AND PLANT

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Abstract. The increasing demand for crop production has resulted in the excessive use of chemical fertilizers and pesticides, which is a problem due to toxic residuals. However, the application of biochar has been used to absorb pesticides to reduce contaminants in soil and increase soil fertility and spring onion growth. The objective of this experiment was to investigate the effects of biochar on chemical residual adsorption in the soil, as well as the yield and growth of spring onions. The experimental field was located at a farm in Nakhon Phanom Province, Thailand. Three treatments were implemented in a randomized complete block design (RCBD) with 4 replications: 1) raw rice husk (RH), 2) rice husk biochar (RHB) and 3) rice straw biochar (RSB). The results showed that the growth of spring onions under RSB and RH was greater than under RHB. The highest fresh yields were obtained when RSB (18 t/ha) was applied, which caused significant improvements in soil fertility, especially due to the high CEC and porosity of RSB. In addition, under biochar amendment, the adsorbed amounts of carbamate (9.18-9.31 mg/kg) and organophosphate (0.20-0.29 mg/kg) pesticides in spring onions decreased compared with those in spring onions in the RH amendment, and the soil concentrations also decreased (<10 mg/kg for both carbamate and organophosphate pesticides). The results suggested that biochar has the potential to reduce the residual chemicals in spring onions and soil more than raw rice husk, which is the current agricultural practice.
Keywords: *adsorption, crop production, residual chemical*

Introduction

Vegetable production in many parts of the world faces problems from the extensive use of chemical pesticides that are harmful to human health and the environment (Shormar et al., 2014). Thailand has problems with low soil fertility and the extensive use of chemical pesticides, especially in spring onion cultivation. From the statistics on the quantity and value of the import of hazardous agricultural substances during years 2011 - 2017, it was found that the number of herbicides, insecticides, and plant disease prevention substances increased annually (Office of Agricultural Economics, 2018). Moreover, the addition of organic materials in the soil has also been found to counteract soil contamination (Khorram et al., 2016).

Biochar is an organic material that is burned under conditions of low oxygen content or no oxygen and high temperature of 300 - 600 ºC, which is called pyrolysis (Bruun, 2011). Biochar is one of the most suitable materials used in agriculture for improving

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physical, chemical, and biological properties of soil (Prendergast-Miller et al., 2014). Biochar is reported to have a positive effect on nutrient and water retention capacity and crop yields such as those of rice (*Oryza sativa*), maize (*Zea mays*), and Chinese chives (*Allium tuberosum*) (Yang et al., 2010; Zimmerman et al., 2011; Kamara et al., 2015; Naeem et al., 2016). It has been recognized that biochar amendment can reduce the bioavailability of pesticides (Ahmad et al., 2014) and enhance the sorption of different pesticides (Kookana, 2010; Chang et al., 2011). Moreover, biochar can reduce pesticide contamination in the soil up to 86 - 88% and lower residue levels of pesticide uptake by spring onions (*Allium cepa* L.) in biochar amended soil (Yu et al., 2009; Khorram et al., 2016) due to the adsorption capability of biochar (Khorram et al., 2016). The adsorption capacity of biochar for pesticides depends on its physicochemical properties, such as the organic carbon content, specific surface area and porous structure (Yu et al., 2009; Dechene et al., 2014). Despite increasing interest in biochar application in soil to improve soil fertility and carbon sequestration, there has not been sufficient knowledge about the effect of different biochar types on the growth and yield of vegetable crops and its efficiency for reducing soil contamination and plant uptake of pesticide residues. The objective of this study was to investigate the effects of biochar increasing the yield of spring onions and its effectiveness in reducing the contamination of pesticides in soil and plant uptake.

Materials and Methods

Biochar production

There were two types of biochar used in this study. Rice husk biochar (RHB) was produced by farmer-traditional kilns at a maximum temperature of 380 ºC, while stove pyrolyzed rice straw biochar (RSB) was produced at an approximate temperature of 550 ºC (*Fig. 1*). Microscopic images of both biochars were obtained using scanning electron microscopy (SEM) (JSM 5410LV, JEOL, Japan). The chemical properties of the biochar are presented in *Table 1*.

Figure 1. *Biochar production used in this experiment: (A) rice husk biochar produced by farmer-traditional kilns and (B) rice straw biochar produced by biochar stoves*

Table 1. *Chemical properties of the rice husk biochar (RHB) and rice straw biochar (RSB) used in the experiment*

Biochar type	pH (1:5 H_2O)	EC (μS/cm)	Total C (%)	Total N (%)	C/N ratio	CEC (cmolc/kg)
RHB	7.8	0.36	33.68	1.14	29	11.45
RSB	8.7	0.96	42.92	1.42	30	15.76

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Experimental site

The experiment was conducted from January 12, 2018, to March 7, 2018, on silt loam soil (Isohyperthermic Oxyaquic (Ultic) Haplustalfs; That Phanom series) at a farmer field in Bueng Lom village, Dong Khwang Subdistrict, Mueang District, Nakhon Phanom Province, Thailand (17º11´09.8´´N, 104º47´35.9´´E) (*Fig. 2*). The soil characteristics were (0-10 cm): pH (H_2O 1:5), 5.60; organic carbon content, 1.10%; cation exchange capacity (CEC), 2.20 cmolc/kg; and available P and exchangeable K, 4.80 mg/kg and 67 mg/kg, respectively. Weather conditions during the experimental period are presented in *Fig. 3*.

Figure 2. *The experimental site at the farmer field*

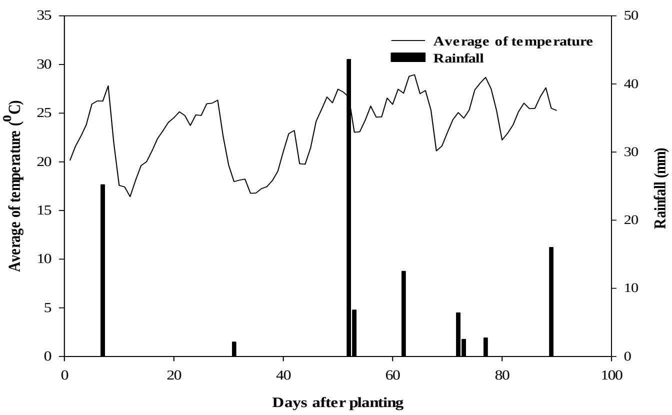

Figure 3. *Daily rainfall (mm) and average temperature (ºC) at the experimental site during the experimental period*

The experimental plots were arranged in a randomized complete block design (RCBD) with three types of organic materials applied 1) raw rice husk (RH; farmer practice), 2) RHB and 3) RSB in 4 replications. One seedling per hill of the "Luplae" variety of spring onion (*Allium cepa* L. var. *aggregatum*) was planted at a spacing of 0.15 m x 0.15 m in the experimental plots of 1 × 2 m then covered uniformly on the soil surface with RH, RHB or RSB for each treatment at a rate of 0.60 kg/plot (3 t/ha). An NPK fertilizer combination of N, P_2O_5 and K_2O (15-15-15) was applied at 0.048 g N/plot, 0.048 g P_2O_5/plot and 0.048 g K_2O/plot to spring onions at 7 days after planting.

The pesticides used in this experiment were carbaryl (a carbamate pesticide) and chlorpyrifos (an organophosphate pesticide) and were applied to each treatment. The

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pesticide solution was a mixture of 20 ml of carbaryl and 30 grams of chlorpyrifos in 20 liters of water and was directly applied to the soil in each plot at a volume of 1000 ml. The pesticide solution was applied to plants at 14, 28, and 42 days after planting.

Data collections

Ten holes of the spring onion plants per plot were sampled at 12 and 20 days after planting to assess growth (height, plant number per hole, fresh weight, and dry weight). At final harvest (54 days after planting), five holes per plot were uprooted, and the number of plants was carefully counted before plants were thoroughly washed with tap water to remove soil particles, air-dried at room temperature for 3 hours and weighed to obtain the fresh weight after oven drying at 70 ºC for 48 hours. The economic return was calculated on a fresh weight basis (t/ha) multiplied by the market price of spring onions (one ton of spring onions = 1,161 USD in January 2018 at the Si Mum Mueang Market, Bangkok, Thailand) and minus biochar production and material costs (400 USD/ha for RH, 504 USD/ha for RHC and 600 USD/ha for RSH).

Fresh spring onion and soil samples (at 0-10 cm soil depth at 10 random locations per plot) were weighed as 1 kg samples in four replications of each treatment and kept in plastic containers at 10 ºC until residual pesticide analysis. Analyses of carbamate and organophosphate pesticides in soil and plant samples were performed using the method according to Steinwandter (1985) Fresenius Z. Anal.Chem no. 1155 and no. 322, respectively.

Statistical analysis

Analysis of variance (ANOVA) was performed to determine treatment effects on various measured parameters. A mean comparison was performed by the least significant difference (LSD) test. The significant level was set as $P \leq 0.05$. The Statistix 8 program (Analytical Software, 2008) was used.

Results

Physical and chemical characteristics of the biochar

The biochar scanning electron microscopy images clearly showed differences in the porous structures of the two biochars (*Fig. 4*), which was strongly influenced by pyrolysis temperature. A greater number of pores and larger macro-pores appeared in RHB than in RSB. Proximate analysis of the biochar showed that RSB had a higher pH (8.7), EC (0.96 µs/cm) and CEC (15.76 cmolc/kg) values than those of RHB (*Table 1*). The total carbon and nitrogen contents of RSB (42.92% and 1.42%, respectively) were higher than those of RHB (33.68% and 1.14%, respectively).

Growth and yield of spring onions

Twelve days after planting, plant height and plant number per hole of the RSB treatment (23 cm and 7 plants/hole) were significantly (P<0.05) higher than those of the RHB treatment (20 cm and 5 plants/hole) but were similar to the RH treatment (22 cm and 6 plants/hole) (*Table 2*). Twenty days after planting, the RSB and RH treatments had a similarly significant effects (P<0.05) on spring onion height. However, the RSB treated spring onions had a lower fresh weight than those treated with RHB and RH

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(*Table 3*). At the final harvest, the fresh weight of the RSB (18 t/ha) and RHB (16 t/ha) onions was significantly higher (P<0.05) than that of RH-treated onions (*Table 4*). Similarly, the economic value of spring onions under RSB (19,828 USD/ha) and RHB (17,834 USD/ha) amendments was significantly greater than that of RH treatment (14,699 USD/ha).

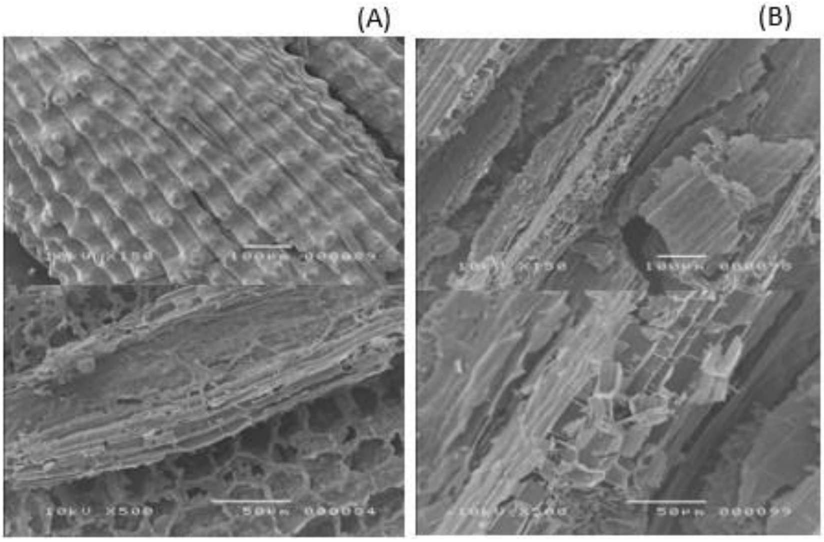

Figure 4. *Scanning electron microscopy (SEM) images of (A) rice husk biochar (RHB) and (B) rice straw biochar (RSB) used in the experiment*

Table 2. *Growth of spring onions at 12 days after planting*[†]

Treatment	Height (cm)	Plant number per hole	Fresh weight	Dry weight
			(g/plant)	
RH	22 ab	6 ab	2.83 a	0.28 a
RHB	20 b	5 b	2.39 a	0.25 a
RSB	23 a	7 a	2.34 a	0.22 a
$LSD_{.05}$	2.37^{*}	1.38^{*}	0.84^{ns}	0.84^{ns}
C.V.(%)	6.34	14.32	19.16	19.39

^{ns} = significantly different at P>0.05 and * = significantly different at P<0.05, [†]a and b represent significant differences between treatments (P<0.05)

Table 3. *Growth of spring onions at 20 days after planting*[†]

Treatment	Height (cm)	Plant number per hole	Fresh weight	Dry weight
			(g/plant)	
RH	25 a	7 ab	5.51 a	0.73 a
RHB	23 b	8 a	3.92 b	0.63 a
RSB	24 ab	6 b	5.13 ab	0.76 a
$LSD_{.05}$	2.14^{*}	1.38^{*}	1.54^{*}	0.23^{ns}
C.V.(%)	5.13	14.32	18.32	0.23

^{ns} = significantly different at P>0.05 and * = significantly different at P<0.05, [†]a and b represent significant differences between treatments (P<0.05)

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***Table 4.** Yield and economic return of spring onions at final harvest*[†‡]

Treatment	Plant number/hole	Fresh weight		Economic value[†] (USD/ha)
		g/plant	t/ha	
RH	7 a	29.25 b	13 b	14,699 b
RHB	7 a	35.53 ab	16 ab	17,834 ab
RSB	6 a	39.58 a	18 a	19,828 a
$LSD_{.05}$	2.43[ns]	6.36[*]	2.83[*]	3,281[*]
C.V.(%)	21.07	15.56	10.56	10.87

[ns] = significantly different at *P*>0.05 and [*] = significantly different at *P*<0.05, [†] Economic value (USD/ha) = (fresh weight (t/ha) × 1,161 USD/t) – biochar production cost, [‡]a and b represent significant differences between treatments (*P*<0.05)

Pesticide uptake in spring onions and soil contamination

The fresh spring onions (including above- and below-ground parts) in the RSB and RHB amended treatments had lower concentrations of carbamate (9.18 and 9.31 mg/kg, respectively) than those in the RH treatments (9.65 mg/kg) (*Table 5*). In addition, plant uptake of organophosphate in RHB and RSB amended soil (0.20 mg/kg and 0.29 mg/kg, respectively) was lower than that in RH amended soil (0.44 mg/kg). Similarly, soil contamination of both carbamate and organophosphate was higher in RH amended soil (0.10 and 0.55 mg/kg, respectively) than in the biochar amended treatments (<0.10 mg/kg for both carbamate and organophosphate).

***Table 5.** The concentration of carbamate and organophosphate contamination in soil and spring onions*[†]

Treatment	Carbamate (mg/kg)		Organophosphate (mg/kg)	
	soil	spring onion	soil	spring onion
RH	0.10 a	9.65 a	0.55 a	0.44 a
RHB	0.04 b	9.31 b	0.08 b	0.20 b
RSB	0.05 b	9.18 b	0.07 b	0.29 b
$LSD_{.05}$	0.04[*]	0.14[**]	0.17[**]	0.11[*]
C.V.(%)	19.86	0.45	23.41	11.49

[*] = significantly different at *P*<0.05 and [**]= significantly different at *P*<0.01, [†]a and b represent significant differences between treatments (*P*<0.05)

Discussion

Biochar quality under different types and conditions

RHB contains pores that are not connected, which may be attributed to insufficient carbonization at low temperatures compared with RSB. On the other hand, RSB produced at a relatively high temperature showed increased cracks and pores compared to those of RHB, which was also observed by Bai et al. (2017) and Peng et al. (2011). Proximate analysis revealed a high ash content in RSB, as indicated by its high EC content (Wu et al., 2012). Deka et al. (2018) also reported that rice straw-derived biochar was highly alkaline relative to its rice husk-derived counterpart. However, the

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EC and CEC properties of biochar are largely determined by its total base content, which varies according to the feedstock type and pyrolysis temperature. The high pyrolysis temperature of 550 ºC for RSB led to a higher base content than that of RHB (380 ºC) as shown by their EC values. The results of Prima et al. (2015) and Wu et al. (2012) corroborated our results.

Effects of biochar on the growth and yield of spring onions

The increase in the growth and yield of spring onions under the biochar amendments (RSB and RHB) resulted from increased soil fertility and nutrient retention. Shackley et al. (2012) and Zheng et al. (2010) reported that the addition of RHB at application rates of 10 t/ha, 40 t/ha, and 41.5 t/ha increased rice grain yield and biological yield by 12%, 14%, and 33%, respectively, compared to that of the control. The results of this study showed that RHB and RSB application increased in spring onion yields by 22% and 35%, respectively, compared with that of RH amendment (current farmer practice).

The high total carbon and nitrogen contents of RSB (42.92% and 1.42%, respectively) followed by RHB (33.68% and 1.14%, respectively) may be due to an increase in the temperature of thermal degradation. The increase in nutrient content with thermal degradation by the loss of volatile compounds (C, H, and O) can be explained by Chan and Xu (2009). Naeem et al. (2016) showed that the concentrations of nutrients were greater in the biochar produced at 500 ºC than biochar produced at lower temperatures, except for N, the content of which decreased as the temperature increased. However, nitrogen is removed through the loss of the ammonium and nitrate fractions as well as the loss of volatile matter containing N groups at a temperature of 200 ºC, but with increased temperatures (>600 ºC), N is gradually transformed into a pyridine-like structure (Bagreev et al., 2001). This is related to our result that RSB had a high N content, which was produced with a high pyrolysis temperature (550 ºC). The influence of biochar on soil physicochemical and biological properties such as its porous structure and high surface area were conducive to the adsorption of water and nutrients (Mishra et al., 2017), which is shown graphically in *Fig. 4*, and the high CEC value of RSB was noted (*Table 1*). However, recent studies indicated that the influence of biochar depends on the feedstock composition (Jindo et al., 2014; Bai et al., 2017; Mishra et al., 2017), pyrolysis process conditions (Pituello et al., 2015; Butnan et al., 2015), biochar particle size and soil environmental conditions (Butnan et al., 2015). High-temperature biochars are expected to have a greater reactivity in soils than low temperature biochars and better contribution to soil fertility due to low volatile matter and high ash contents and a fixed C content (Butnan et al., 2015).

Effect of biochar on pesticide uptake by plants and contamination in soil

Biochar amendments increased the adsorption of pesticides in soil with a subsequent decrease in the plant uptake of carbamate and organophosphate pesticides by 3.52 - 4.87 and 34.09 - 54.50%, respectively, relative to that of spring onions grown in raw rice husk-amended soil. According to Yu et al. (2009), significantly lower residue levels of chlorpyrifos and carbofuran in spring onions were found under red gum wood chip biochar amendment compared with that observed under cultivation in unamended soil. Similarly, Khorram et al. (2015) reported that rice husk biochar amendments resulted in significantly enhanced fomesafen adsorption. Additionally, the pesticide adsorption capacity of biochar depends on its physicochemical properties such as pH (Yao et al., 2012), cation exchange capacity (Cheng et al., 2008), carbon content, and porous

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structure (Dechene et al., 2014). Moreover, our rice straw biochar amendment stimulated plant growth and reduced pesticide contamination in plants and soil by adsorption due to its higher CEC and porosity than those of rice husk biochar and raw rice husk. Numerous studies have reported that biochar amendments decrease pesticide desorption, degradation and plant uptake because of their remarkably high pesticide adsorption capacities (Spokas et al., 2009; Yu et al., 2010; Khorram et al., 2015), which depend on decreased pesticide desorption, pyrolysis conditions and feedstocks (Ding et al., 2016).

Conclusions

This study demonstrated the beneficial effects of biochar amendment on increasing plant production. Thus, the results suggested that replacing raw rice husk and/or rice straw with biochar in soil amendment practices led to altered nutrient cycling in soils, increased retention of pesticides in soil and reduced contents of pesticide residues in agricultural produce. Future research to fill pertinent knowledge gaps may allow to determine the optimum amount of biochar required to reduce pesticide residues.

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