STRAW RETURN WITH BIOCHAR INCREASED SOIL MACRO-AGGREGATES AND IMPROVED FLUE-CURED TOBACCO (*Nicotiana tabacum* L.) YIELD AND QUALITY

JIANG, C.[1] – ZU, C.[1] – WANG, H.[2] – YAN, Y.[1] – LIU, Y.[3] – SHEN, J.[1*]

[1]*Tobacco Research Institute, Anhui Academy of Agricultural Sciences, Hefei 230031, China (e-mail: chaoqjiang@163.com (Jiang, C.); lcz2468@sina.com (Zu, C.); feng9686@163.com (Yan, Y.))*

[2]*Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, PR China (e-mail: 656490434@qq.com (Wang, H.))*

[3]*Anhui provincial tobacco company, Hefei 230031, China (e-mail: clonelin@163.com (Liu, Y.))*

[*]*Corresponding author*
e-mail: shenjia0000@126.com; phone: +86-551-6514-8987; fax: +86-551-6514-8991

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Abstract. Straw return and biochar are often applied to improve soil fertility and increase crop yield. However, the effects of these practices on soil aggregates and tobacco leaf yield and quality are still unclear. Five treatments: no straw (CK), application of rice straw (RS), tobacco straw biochar (TSB), RS plus TSB (RS+TSB), and RS plus pig manure (RS+PM) were conducted to evaluate the effects of straw return and biochar on soil aggregates, tobacco leaf yield and quality in Southern Anhui, China. Results showed that TSB significantly increased soil pH by 0.38. The RS+TSB and RS+PM significantly increased the contents of soil organic matter, available nitrogen (N) and potassium (K). Biochar and straw return increased >5 mm aggregates fraction in topsoil (0-20 cm) with an order of RS+PM > RS+TSB > TSB > RS. The RS+TSB and RS+PM significantly increased the yield, appearance and sensory quality of tobacco leaf. The leaf yield and quality were positively correlated with >5 mm aggregates fraction, but negatively correlated with <0.25 mm aggregates. These results indicated that straw return with pig manure (375 kg ha^{-1}) or biochar (1050 kg ha^{-1}) increased the yield and quality of tobacco leaf, likely due to their effect on large soil aggregate and the available of macronutrients in soil.
Keywords: *tobacco-planting soil, soil quality, sensory quality of tobacco leaf, aggregate fractions, pig manure*

Introduction

Flue-cured tobacco (*Nicotiana tabacum* L.) is an essential economic crop in China, and the yield and quality of tobacco leaves are closely related to the soil structure and fertility (Zheng et al., 2019; Jiang et al., 2020). However, soil hardening and nutrient imbalance are prevalent in tobacco growing areas in China due to the long-term excessive application of chemical fertilizer and less input of organic fertilizer, which significantly affect the growth and development of tobacco plants, leading to the decline of tobacco leaf yield and quality (Mu et al., 2017; Jia et al., 2020). Therefore, it is urgent to improve the soil structure and quality of tobacco fields. At present, studies on soil improvement were mainly focuses on straw return, organic manure application, biochar application and green manure planting and so on (Lehmann, 2007; Jia et al., 2020). As a common organic material, reasonable application of straw return can improve the soil physical and chemical properties. It was reported that straw return significantly improved soil

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structure, physical and chemical properties, and increased the percentage of macro-aggregates (Sun et al., 2012; Wang et al., 2010; Jia et al., 2020). Sun et al. (2012) found that straw return not only significantly increased the percentage of macro-aggregates, but also increased their organic carbon content. Bo et al. (2014) also reported that soil organic matter content increased with the increasing of amount of straw return. In addition, straw return combined with chemical fertilizer effectively reduced soil bulk density and improved soil physical condition (Lu et al., 2019). Therefore, straw return plays an important role in increasing soil organic matter, improving soil structure and fertility.

Biochar application is also commonly used in soil melioration. Biochar could increase soil organic carbon and cation exchange capacity (CEC), reduce nutrient loss, and therefore increase crop yield and quality (Lehmann, 2007; Laird et al., 2010; Sagrilo et al., 2015). Biochar also improves soil structure, enhances soil aeration and water retention, and enhances soil aggregate composition and stability (Wu et al., 2012; Zong et al., 2016). However, laboratory culture experiments showed that biochar application did not increase the content of large aggregates and even reduce the stability of soil aggregates (Busscher et al., 2010; Hou et al., 2015). Therefore, the effects of biochar on soil aggregates are unclear. More experiments are needed to clarify the effects of biochar on soil aggregates in both field and laboratory condition.

Tobacco growing area in southern Anhui is a typical tobacco-rice rotation region in China. In recent years, due to the increase of multiple cropping and the extensive application of chemical fertilizer, soil quality has declined significantly, such as soil acidification, soil hardening, and nutrient imbalance, which significantly decreased the yield and quality of tobacco leaves, and also reduced the income of tobacco planting and farmers (Zheng et al., 2019; Wang et al., 2020). Therefore, it is imperative to improve the soil quality of tobacco field in Southern Anhui, China. In tobacco-rice rotation region, a large amount of straw resources is produced after rice harvest, but most of them did not been utilized efficiently due to lack of reasonable straw returning method (Zheng et al., 2019). Therefore, in this study, we explored the effects of straw return and biochar application on the soil aggregates characteristics, and the yield and quality of tobacco leaf in Southern Anhui, China. The results of this study will provide guidance for the efficient utilization of straw, soil conservation and tobacco leaf quality improvement in tobacco-rice rotation region.

Materials and methods

Field experimental site

The field experiments were conducted from 2018 to 2019 (two growing seasons) in Yangliu Town (118°37'56", 30°49'35"), Xuancheng City, Anhui Province, China, which is a typical a tobacco-rice rotation area. The experimental site is a low hilly area with subtropical humid monsoon climate, with an average annual air temperature of 15.9℃ and 1294 mm annual precipitation. The rainfall was 528.4 mm and 467.9 mm during March and July (the tobacco growing period) in 2018 and 2019, respectively. The average air temperature was from 12.7℃ to 29.4℃, and from 11.9℃ to 28.2℃ during March and July in 2018 and 2019, respectively. The soil type of the experiment field is paddy soil, with an initial pH of 5.52, 16.8 g kg^{-1} organic matter, 86.2 mg kg^{-1} alkali-hydrolyzed N, 21.3 mg kg^{-1} available phosphorus (P) and 126.7 mg kg^{-1} available K in the 0-20 cm soil layer.

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Experimental design

Five treatments were established in the study: no straw (CK), an application of 2700 kg ha^{-1} rice straw (RS), an application of 2250 kg ha^{-1} tobacco straw biochar (TSB), an application of 1350 kg ha^{-1} rice straw and 1050 kg ha^{-1} tobacco straw biochar (RS+TSB), 2400 kg ha^{-1} rice straw and 375 kg ha^{-1} pig manure (RS+PM). The amount of rice straw, tobacco straw biochar and pig manure used in the treatments was designed based on an equal carbon (1000 kg ha^{-1}) input to the field. The amount of rice straw, tobacco straw biochar was calculated by dry matter, and the water content of pig manure was 40%. RS, TSB and PM had average total carbon content of 372.3, 453.8, 256.6 g kg^{-1} and total nitrogen content of 12.6, 11.8, 315.7 g kg^{-1} on a dry matter basis, respectively. The rice straw, tobacco straw biochar and pig manure were evenly spread on the soil surface of the plot, and mixed fully with soil a rotary tiller, and then fertilized and ridged. All the fertilizers were applied in a band way before ridging. Fertilizers application rate was 115 kg N ha^{-1}, 157.5 kg P_2O_5 ha^{-1} and 315 kg K_2O ha^{-1}. All the treatments were replicated three times in the randomized complete block design. The plot area was 36 m^2 (7.5 m long and 4.8 m wide), with four rows of plants in each plot. Tobacco seedlings were planted in rows, 120 cm between rows and 50 cm between plants at a depth of 15 cm. The variety of flue-cured tobacco planted was “Yunyan 97”. After the harvest of tobacco leaves, all plots were planted rice, and the fertilization and field management were identical in all treatments. The fertilizers were 75 kg ha^{-1} urea (N 46%) and 150 kg ha^{-1} compound fertilizer (N:P_2O_5:K_2O = 15:15:15) during rice planting. The field experiment was repeated in 2019, and all the treatments and operations were exactly the same as in 2018. Tobacco seedlings were transplanted on March 22, 2018 and March 26, 2019. Tobacco leaves were harvested from June 10, 2018 and June 12, 2019, and the leaves were harvested four times by hand at 7- or 8-day intervals, by removing three to four leaves each time. Other cultivation measures including plant protection were carried out according to the technical guidelines recommended by Tobacco Research Institute, Anhui Academy of Agricultural Sciences. Photos of the experimental culture were shown in *Fig. 1*.

Figure 1. *Photos of fertilization and ridging stage of the experiment (left) and 75 days after transplanting (right) in 2018*

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Sampling and measurements

Before the experiment started, soil samples of surface layer (0-20 cm) were collected to determine the basic fertility. After tobacco harvesting, soil samples were collected on July 15, 2019. S-type sampling method was used to collect soil samples (0-20 cm) in the middle of two plants on a row of each plot. At the same time, the undisturbed soil was collect and put into a plastic box with a volume of 10 cm×8 cm×5 cm, and minimized the damage to the undisturbed soil in the process of collection. Physicochemical properties of the topsoil soil (0–20 cm) were determined according to the method of Bao (2007). Soil aggregates were determined according to the method of Zhou et al. (2007), and divided into five aggregate size fractions: >5 mm, 2-5 mm, 1-2 mm, 0.25-1 mm, <0.25 mm.

The mature tobacco leaves were harvested separately in each plot, and cured immediately in a flue-curing barn. The cured leaves were classified according to the grading standards of flue-cured tobacco, and the trade yield and output value were calculated. About 1.0 kg of the cured central tobacco leaves were randomly selected from each treatment for evaluating the appearance and sensory quality according to the methods of Karaivazoglou et al. (2007). Appearance quality and sensory quality was evaluated by three experts from China Tobacco Anhui Industrial Co. LTD, according to the Standard of the People’s Republic of China (GB2635-1992, 1992; GB5606.4-2005, 2005). There were seven indices for appearance quality: color, maturity, identity, leaf structure, oil content, and color intensity. Ten indices for sensory quality: odor quality, odor amount, offensive odor, smoke content, vigour, exquisite degree, irritation, dry sensation, remaining taste and sweetness. At the same time, about 1.0 kg of the cured central leaves were randomly selected for chemical analysis. Samples were dried to constant dry weight at 70°C, and milled into powder. The content of total nitrogen, nicotine, total sugar, reducing sugar, potassium and chlorine in tobacco leaves was determined by Continuous Flow Analysis according to the method of Wang (2003).

Statistical analyses

Data analysis was conducted using one-way ANOVA with SPSS 19.0 (SPSS Inc., Chicago, IL, USA). Least significance difference (LSD) test was performed for the comparisons of the means at $P < 0.05$. Pearson correlations were used to analyse the relationships between leaf yield, output value, appearance quality, sensory quality, >5 mm aggregates, 5-2 mm aggregates, 2-1 mm aggregates, 1-0.25 mm aggregates and 1-0.25 mm aggregates parameters.

Results

Tobacco leaf yield and output value

As shown *Fig. 2*, the RS+TSB and RS+PM significantly increased the leaf yield by 7.9% and 6.7% compared with the CK, respectively, while there was no significant difference in the leaf yield among the RS, TSB, and CK. Similarly, RS+TSB significantly increased the output value of tobacco leaf by 9.3% compared with the CK. However, there was no significant difference of the output value of tobacco leaf in the other treatments. Short-term straw return did not increase the yield and output value of tobacco leaf, but straw return combined with biochar (RS+TSB) significantly increased the yield and output value of tobacco, and the RS+PM also increased the tobacco leaf yield.

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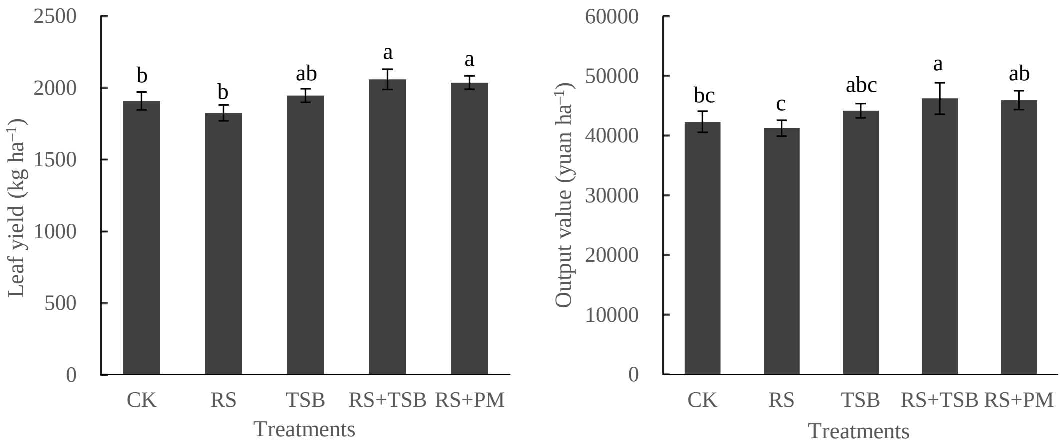

***Figure 2.** Effects of different treatment on yield and output value of tobacco leaf. Vertical bars indicate standard error of mean (n = 3). Columns with different lowercase letters indicate significant differences (P < 0.05)*

Tobacco leaf appearance and sensory quality

No significant difference was found in the appearance and sensory quality of cured leaves between the CK and RS (*Fig. 3*). However, the TSB, RS+TSB and RS+PM significantly increased the appearance quality of cured leaves by 11.2%, 10.3% and 9.6% compared with CK, respectively. Similarly, the TSB, RS+TSB and RS+PM significantly enhanced the sensory quality of cured leaves by 4.7%, 4.5% and 6.6%, respectively. There was no significant difference in the appearance quality and sensory quality of cured leaves among TSB, RS+TSB and RS+PM.

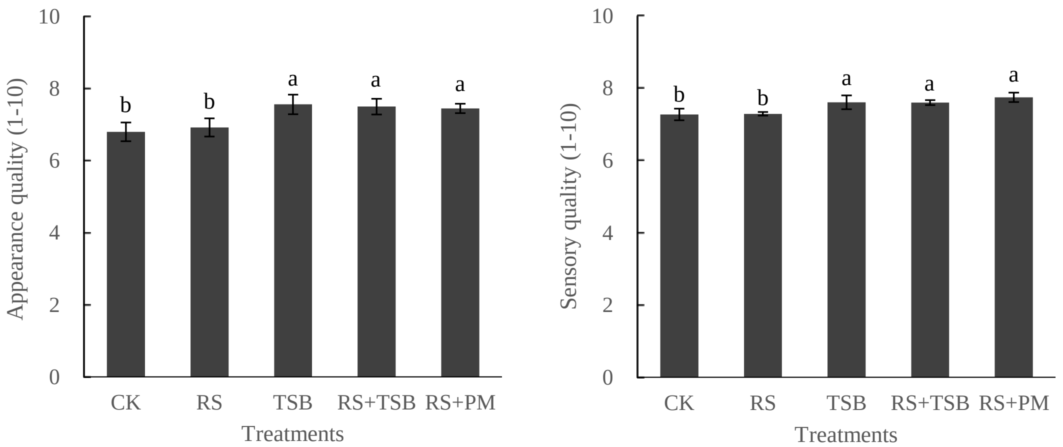

***Figure 3.** Effects of different treatment on appearance and sensory quality of tobacco leaves. Vertical bars indicate standard error of mean (n = 3). Columns with different lowercase letters indicate significant differences (P < 0.05)*

Tobacco leaf chemical composition

As shown in *Table 1*, the CK had the lowest contents of total N and nicotine content in cured leaves, while RS+PM significantly increased the total N and nicotine content in

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cured leaves by 11.7% and 12.9%, respectively, compared with the CK. In addition, the K content of the cured leaves in the RS+PM (2.2%) was significantly increased by 13.9% compared with the CK. There was no significant difference in the contents of total sugar, reducing sugar and chlorine in cured leaves in all treatments.

Table 1. *Effect of different treatment on chemical components content of cured leaves*

Treatment	Total N content (%)	Nicotine content (%)	Total sugars (%)	Reducing sugars (%)	K content (%)	Cl content (%)
CK	1.80 b	1.86 b	26.07 a	22.18 a	1.93 b	0.18 a
RS	1.99 ab	2.05 a	25.49 a	21.05 a	2.16 ab	0.21 a
TSB	1.94 ab	1.97 ab	26.88 a	22.76 a	1.98 ab	0.19 a
RS+TSB	1.96 ab	2.00 ab	26.60 a	22.91 a	2.07 ab	0.19 a
RS+PM	2.01 a	2.10 a	27.25 a	22.51 a	2.20 a	0.16 a

Means followed by different lowercase letters within a column indicate a significant difference ($P < 0.05$)

Soil physicochemical properties of the topsoil soil

As shown in *Table 2*, the TSB and RS+TSB significantly increased the soil pH by 0.40 and 0.38, respectively, compared with CK, while there was no significant difference in pH among the CK, RS and RS+PM. The RS, RS+TSB and RS +PM significantly increased the soil organic matter content. Moreover, the RS+TSB and RS +PM also significantly increased the soil CEC. The RS and RS +PM significantly enhanced the soil DOC. Therefore, straw return increased the soil organic matter and DOC, while the biochar application increased the soil pH.

Table 2. *Effects of different treatments on soil pH, organic matter, CEC and DOC*

Treatment	pH	Organic matter (g kg^{-1})	CEC (cmol kg^{-1})	DOC (mg kg^{-1})
CK	5.56 b	14.69 b	7.36 b	134.94 b
RS	5.64 b	15.83 a	7.62 ab	162.28 a
TSB	5.96 a	14.78 b	7.87 ab	144.68 ab
RS+TSB	5.94 a	15.62 a	8.13 a	155.03 ab
RS+PM	5.59 b	16.02 a	7.97 a	162.09 a

Means followed by different lowercase letters within a column indicate a significant difference ($P < 0.05$)

The RS, RS+TSB and RS+PM significantly increased the soil total N and total K compared with the CK (*Table 3*). There was no significant difference in soil total P among all treatments. The TSB, RS, RS+TSB and RS+PM significantly increased soil available N by 12.4%, 10.9%, 11.5% and 13.6%, and increased soil available N by 24.6%, 17.5%, 19.0% and 24.4%, respectively. Moreover, RS, RS+PM and RS+TSB also significantly increased soil available K by 25.6%, 15.3% and 26.3%, respectively. Therefore, straw return could increase the soil available N, P and K content.

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***Table 3.** Effects of different treatments on soil N, P and K concentration*

Treatment	Total N (g kg^{-1})	Total P (g kg^{-1})	Total K (g kg^{-1})	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
CK	0.99 b	0.43 a	10.66 b	90.78 b	22.57 b	133.16 c
RS	1.07 a	0.40 a	11.42 a	102.05 a	28.12 a	167.12 a
TSB	0.99 b	0.46 a	11.09 ab	100.66 a	26.52 a	147.21 bc
RS+TSB	1.08 a	0.43 a	11.20 a	101.26 a	26.86 a	153.60 ab
RS+PM	1.09 a	0.46 a	11.44 a	103.15 a	28.08 a	168.16 a

Means followed by different lowercase letters within a column indicate a significant difference ($P < 0.05$)

Soil aggregate composition

As shown in *Fig. 4*, straw return and biochar application significantly increased >5 mm size fraction aggregates compared with the CK. The proportion of >5 mm size fraction was highest in RS+PM, which was 9.0% more than that in CK. There was no significant difference in 5-2 mm size fraction in all treatments. However, the TSB, RS+TSB and RS+PM significantly increased the content of <0.25 mm size fraction compared with the CK. Therefore, straw returning combined with pig manure (RS+PM) or biochar (RS+TSB) significantly increased the proportion of >5 mm size fraction, while reduced <0.25 mm size fraction.

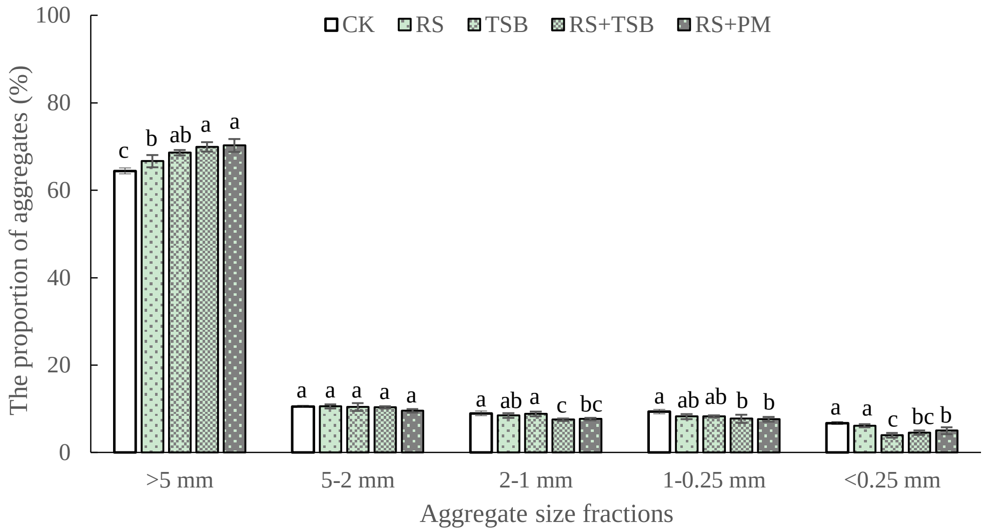

***Figure 4.** Effects of different treatments on soil aggregate composition. Vertical bars indicate standard error of mean (n = 3). Columns with different lowercase letters within the same aggregate fractions indicate significant differences (P < 0.05)*

Relationship between tobacco yield and soil aggregate composition

As shown in *Table 4*, both the yield and output value of cured leaves were significantly positively correlated with the proportion of >5 mm aggregates, while the output value of cured leaves was negatively correlated with 1-0.25 mm and <0.25 mm aggregates. The appearance and sensory quality of cured leaves were positively correlated with the

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proportion of >5 mm aggregates, but negatively correlated with <0.25 mm aggregates. Thus, the yield and quality of tobacco cured leaves were significantly positively correlated with the proportion of >5 mm aggregates, but negatively correlated with <0.25 mm aggregates.

Table 4. *Relationship between tobacco yield and soil aggregate composition*

	Leaf yield	Output value	Appearance quality	Sensory quality	>5 mm aggregates	5-2 mm aggregates	2-1 mm aggregates	1-0.25 mm aggregates	1-0.25 mm aggregates
Leaf yield	1								
Output value	0.876**	1							
Appearance quality	0.613*	0.667**	1						
Sensory quality	0.598*	0.681**	0.732**	1					
>5 mm aggregates	0.575*	0.631*	0.675**	0.724**	1				
5-2 mm aggregates	-0.299	-0.145	-0.342	-0.274	-0.528*	1			
2-1 mm aggregates	-0.437	-0.385	-0.415	-0.546*	-0.754**	0.537*	1		
1-0.25 mm aggregates	-0.437	-0.589*	-0.359	-0.553*	-0.820**	0.191	0.563*	1	
1-0.25 mm aggregates	-0.476	-0.599*	-0.734**	-0.652**	-0.784**	0.137	0.286	0.566*	1

* indicate significance at the level of 0.05, ** indicates significance at the level of 0.01

Discussion

Effects of straw return and biochar on yield and quality of tobacco leaf

Previous studies had proved that both straw return and biochar application could significantly increase the growth and yield of many crops. In this study, tobacco straw biochar, especially tobacco straw biochar with rice straw return significantly improved the growth of tobacco plant, increased the yield and output value of flue-cured tobacco leaves (*Fig. 2*). Similarly, biochar have been proved to improve the growth and yield of corn (Oguntunde et al., 2008), rice (Lehmann et al., 2003), wheat (Van Zwieten et al., 2010) and so on. Studies have also found that straw return could improve the yield and quality of tobacco leaves (Zheng et al., 2019; Lu et al., 2019). Straw return significantly reduced the soil bulk density of topsoil, improved the soil hydrothermal conditions and nutrient supply, and thus promoted the plant growth and development, and increased crop yield (Lu et al., 2019). Tan et al. (2018) found that the application of 1500 kg ha^{-1} tobacco straw biochar significantly promoted the growth of flue-cured tobacco and increased the yield of tobacco leaves. The promotion effect of biochar application on promoting crop growth was mainly due to the improvement in soil physical and chemical properties, the increase on soil nutrient availability, and the improvement in soil microbial abundance and community structure (Van Zwieten et al., 2010). Tan et al. (2018) found that the returning of tobacco straw biochar to the field significantly promoted the reproduction of bacteria and actinomycetes, while reduced the number of soil fungi in the in the continuous cropping tobacco soil, which had a remarkable effect on decreasing tobacco bacterial wilt. In this study, the incidence of tobacco bacterial wilt in all treatments was

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relatively low, and there was no significant difference between treatments (data not shown), which may be due to the fact that the soil in the tobacco-rice rotation areas underwent crop rotation through flood and drought, therefore, the tobacco bacterial wilt was relatively low (Kong et al., 2007).

Effects of straw return and biochar on soil physicochemical properties

Many studies showed that biochar application could increase soil pH (Van Zwieten et al., 2010; Yuan and Xu, 2010). In this study, it was found that the application of tobacco straw biochar significantly increased the soil pH. Previous research results showed that the application of biochar with fertilizer increased the soil pH by 0.19 and 0.27 in yellow brown soil and red soil, respectively (Yuan and Xu, 2010). The effect of biochar on increasing soil pH increased with the increase of its application amount (Van Zwieten et al., 2010). Due to the biochar contains base ions such as Ca^{2+}, K^{+} and Mg^{2+}, some of these cations are released to exchange H^{+} and Al^{3+} in the soil when it was applied to the soil, and thus reducing the acidity of the soil, increasing the base saturation and pH of the soil (Topoliantz et al., 2005; Van Zwieten et al., 2010). The soil of continuous tobacco cropping system is seriously acidified and has a low pH (Jiang et al., 2020). Therefore, the biochar can be used to neutralize the acid and increase the pH of the tobacco-growing soil.

Biochar contains a lot of soluble mineral nutrients, which can improve the level of available nutrients in soil after its application. In this study, tobacco straw biochar significantly increase the contents of available N, P and K in tobacco planting soil (*Table 3*). The increase in soil fertility by biochar application is most likely due to its ability to absorb cations (Atkinson et al., 2010). It was reported that, after the applied of biochar to the soil, its surface could be oxidized to form a carbonyl, phenolic and quinone groups, and the adsorption capacity of soil cations can be increased in the oxidized biochar (Atkinson et al., 2010). Glaser et al. (1998) found that adding bamboo charcoal could significantly increase the exchangeable base ions in the soil. This present study was consistent with the results of Glaser et al. (1998), we found that the application of tobacco straw biochar in the tobacco field significantly increased the soil CEC.

The present study show that straw return significantly increased the soil organic matter content (*Table 2*), which is consistent with the research results of Bo et al. (2014). It was reported that the soil organic matter content of tobacco field increased to varying degrees with the increasing of the amount of corn and wheat straw returned to the field (Bo et al., 2014). As most of the straw is organic composition, among them, the cellulose, hemicellulose and protein complex are difficult to be decomposed by microorganisms, which will be remain in the soil to form organic matter. On the other hand, straw return to the field could enhance the activity and aromatization degree of soil humus, maintain the balance of soil organic matter (Bo et al., 2014). In addition, the straw contains a large number of nutrient elements, which plays an important role in soil fertilization. The results of this study showed that straw return increased the soil available N, P and K to varying degrees, which is similar to the results of Wang et al. (2010) and Zheng et al. (2019).

Effects of straw return and biochar on soil aggregates

As a basic unit of soil structure, the content and stability of soil aggregates have an important role in soil water and fertilizer conservation ability (Yin et al., 2015). In this study, the application of biochar with straw significantly increased the proportion of

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>5 mm aggregates in surface soil (0-20 cm), and it was in the roder: RS+PM > RS+TSB > TSB > RS > CK, while significantly decreased the content of <0.25 mm aggregates. This is consistent with previous studies (Qiao et al., 2018; Jia et al., 2020). Jia et al. (2020) also found that biochar and straw application significantly increased the proportion of 0.5-1.0 mm aggregates in the 0-20 cm soil layer, and significantly reduced the proportion of <0.25 mm aggregates. On the one hand, the biochar can promote the formation of macro-aggregates due to its porous structure and large specific surface area (Brodowski et al., 2006). On the other hand, the application of biochar increased the content of soil organic carbon, which as a good soil cementing agent, also promoted the formation of macro-aggregates (Puget et al., 2000; Abiven et al., 2009; Jia et al., 2020). After applied in the soil, the straw served as the core for the formation of large aggregates (Wang et al., 2015), and after the straw decomposition, the content of carbohydrate, aromatic and aliphatic carboesters, ester compounds and amino compounds in the soil will be increased. Carbohydrates are the important binders for soil aggregates, which play an important role in the formation and stability improvement of soil aggregates (Yousefi et al., 2008; Wang et al., 2018). In this study, RS+PM and RS+TSB treatments had the best effect on increasing the proportion of >5 mm aggregates, which may be the result of the complementary effect of biochar and straw, as well as the effect of pig manure on straw decomposition.

It was reported that the application of exogenous carbon can promote the formation of >0.25 mm aggregates in soil, particularly for increasing the proportion of 1-2 mm grain size aggregates (Puttaso et al., 2013). Bo et al. (2014) conducted field experiments on brown soil in Shandong for four consecutive years and found that continuous return of corn straw to the field promoted the formation of soil aggregates and improved its stability. In this study, the RS and TSB had less significant effect on soil aggregates improvement than that of RS+PM (*Fig. 3*). This result also suggested that although straw return is beneficial to the formation of aggregates, it needs to be applied for a long time to have good effects (Abiven et al., 2009; Bo et al., 2014). In addition, because flue-cured tobacco is a dry season crop, the soil in the tobacco field did not cover all the rice straw completely to form an anaerobic and high-humidity environment, leading to slow decomposition of the wax layer outside the straws (Zhu et al., 2018), therefore, rice straw return alone could not improve soil aggregates effectively in a short time. However, rice straw combined with pig manure or biochar can effectively improve the soil aggregates.

In this study, it was found that the yield and quality of tobacco leaf were significantly positively correlated with the proportion of >5 mm aggregates, but negatively correlated with <0.25 mm aggregates. Both the application of biochar and straw significantly increased the proportion of >5 mm aggregates in surface soil (0-20 cm). This study suggested that the application of tobacco straw biochar, especially the application of biochar combined with straw promoted the growth of tobacco plant and increased the yield and output value of tobacco leaf. Therefore, straw return with pig manure or biochar could be used to improve soil aggregate structure, increase soil nutrient, and enhance the yield and quality of tobacco leaf. However, more experiments need to be carried out to explore the effects of long-term straw return on the yield and quality of tobacco leaf and soil conservation.

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Conclusion

The present study concluded that the application TSB significantly increased pH by 0.38 in the tobacco field soil, and more studies are needed to elucidate the mechanism of tobacco straw biochar on soil acidity. Biochar and straw return increased the proportion of >5 mm aggregates in topsoil (0-20 cm) with an order of RS+PM > RS+TSB > TSB > RS. The RS+TSB and RS+PM significantly increased the yield, appearance and sensory quality of tobacco leaf. The yield and quality of tobacco leaf significantly positively correlated with the proportion of > 5 mm aggregates, but negatively correlated with <0.25 mm aggregates. Therefore, straw return with pig manure (375 kg ha^{-1}) or biochar (1050 kg ha^{-1}) could be used to improve soil aggregate structure, increase soil nutrient, and enhance the yield and quality of tobacco leaf.

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