Tobacco Growth Responses and Soil Properties to Rice-straw Biochar Applied on Yellow-brown Soil in Central China

Jixu ZHANG¹,²,a, Zhong-Feng ZHANG¹, Guo-Ming SHEN¹, Rui WANG³,b, Lin GAO¹, Yan-Chen DAI¹, Ting ZHA¹, Ji-Guang ZHANG¹,²

¹Tobacco Research Institute, Chinese Academy of Agricultural Sciences, Qingdao 266101, Shandong, China
²Qingdao Agricultural University, Qingdao 266109, Shandong, China
³Enshi Branch of Hubei Tobacco Company, Enshi 445000, Hubei, China

a zhangjixu2088@126.com, b wangrui2999@126.com,

Corresponding author

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Abstract. Pot experiments were conducted to study the effect of straw biochar application on tobacco growth and soil fertility. The growth of ground parts of tobacco was promoted by biochar application at appropriate levels (0.2-1.0%), while it was inhibited by high-level (5%) biochar application. The growth of root system was promoted more extensively by biochar application at all levels tested than was the growth of the aboveground organs, with 5% biochar addition resulting in the highest root-shoot ratio, which also delayed the senility of the root system, including of lateral roots. The taproot length, the first- and second-order lateral roots and the root-shoot ratio of tobacco increased during the early growth stage but decreased at latter growth stage in all treatments. Moreover, with the increasing amount of biochar applied, soil pH and soil nutritional indicators including organic carbon, alkali-hydrolysable N, available P and available K increased with the highest value was observed in the 5% biochar treatment. Our results suggested that straw biochar application at appropriate levels (0.2-1.0%) would lead to an increase in soil fertility and promote tobacco growth. The field experiments are required to test the effect of biochar application on tobacco growth and soil environment with different soil types in tobacco planting area in China.

Introduction

According to preliminary statistics, China produces 0.6-0.7 billion tons of straw each year, accounting for 30% of the world annual production, of which more than 50% are directly burned in the field, abandoned at the edge of the field, or combusted as cooking and heating fuel [1]. This is not only a great waste of natural resources but also a significant source of air pollution [2]. Hence, the conversion of crop straw into biochar is causing more and more attention in China, and it could be a beneficial soil amendment as a novel crop straw management [3].

Biochar refers to the products obtained from pyrolysis and slow carbonization of crop stalks, wood, animal waste and garbage under the lack of oxygen and high temperature (usually < 700 °C) [4]. Biochar is rich in carbon, and has good porous structure, large porosity, and surface area. These properties make biochar an excellent material for use in agricultural production and
environmental protection [5]. As a form of agricultural waste, straw poses universal problems, such as low effective utilization rate and environmental pollution caused by direct combustion [6]. In the fields, application of biochar obtained from carbonized straw, not only replenishes organic carbon in the soil, increases nitrogen immobilization and soil fertility, but also maintains soil nutrients balance and soil structure, improves the absorption of nutrients by crops, thus improving crop productivity [7,8]. The beneficial effect of biochar on the physical and chemical properties of soil helps to improve the soil’s ecological function, which has great significance in promoting crop growth and development. Many studies show that application of a certain amount of biochar in the field causes increase in the growth and yield of the crops such as corn, wheat and rice to different extents [9-11].

Currently there is little knowledge on the effect of straw biochar on tobacco growth and development, and on soil properties. Hence, The objectives of this study was to investigate the effect of different amounts of straw biochar on the growth and development of tobacco in aboveground and underground and soil fertility by a pot experiment using yellow brown soil, which may provide theoretical basis and practical guidance for the application of straw biochar in flue-cured tobacco field in China in the near future.

Materials and Methods

Pot experiments were conducted in the greenhouse of the "Qing Jiang Yuan" modern tobacco agriculture science and Technology Park in Enshi, Hubei province, Central China, in 2013. Arable-layer soil collected from the local tobacco field at Mao Bacao Village, was tested. The soil type was yellow-brown soil. The physi-chemical properties of the soil were as follows: pH 6.9, soil organic matter 19.23 g/kg, alkali-hydrolysable nitrogen (N) 85.37 mg/kg, available phosphorus (P) 62.70 mg/kg, and available potassium (K) 318.67 mg/kg. The tobacco variety Yunyan 87 was used. The tested soil was left to dry naturally, after which the roots and incursive bodies were picked out, crushed and sieved to 2-mm mesh. The biochar was derived at 550 °C for 8 h from rice straw. Its physical and chemical properties were as follows: pH 9.20, total carbon content 630 g/kg, total nitrogen content 13.5 g/kg, ash content 140 g/kg, total phosphorus 4.50 g/kg, and total potassium 21.5 g/kg. Biochar was thoroughly mixed with the soil. Fifteen kilograms of mixed soil was used per pot, and irrigated with enough water to make the soil settle. A consistently growing, disease-free tobacco seedling was planted in each pot. These pots were irrigated with water every 3-5 d during the whole growth period, so as to keep the soil moisture content 60 % of field capacity by weight. The fertilization amount was referenced to local fertilization standards, and the total nitrogen was 105 kg per hectare, with N: P₂O₅:K₂O=1:1.5:3. All fertilizers were applied as basal fertilizers before tobacco transplanting.

Experimental Design

For the pot experiment, we used a control and three treatments with straw biochar applied at three different levels, each one repeated 15 times. The treatments were T0: Conventional control, no biochar (0 g/kg dry soil); T1: 0.2 % biochar; T2: 1.0 % biochar and T3: 5.0 % biochar. The biochar amount added was calculated by the soil density and the biochar yield of rice straw [12].
Sampling and Analysis

After transplanting, five pots per treatment were used to observe the growth and development and record the main agronomic characters indices of tobacco at the resettling stage and squaring stage. Leaf area was calculated from the literature [13]. Three representative tobaccos were selected at different development stages (resettling stage, vigorous growth stage, squaring stage and flat-topped stage); the entire root systems was dug out and rinsed thoroughly. Following this, the growth of root system was observed, the lengths of main root, first-order lateral roots and second-order lateral roots were recorded, and volume, fresh weight, and dry weight of the root system were measured. The oven method of 65 °C for 72 h was adopted for dry weight determination, and the root volume was determined by the drainage method [14].

In addition to the sampling of the root system, the roots, stems, and leaves of tobacco plants were sampled. All selected samples were heated at 105 °C for 30 min and then dried at 65 °C for 72 h to constant weight, and the weight of the dry matter was measured. And samples of tobacco root, stalk and leaves of different treatment at flat-topped stage were measure the nitrogen, phosphorus and potassium concentration.

The whole root system of tobacco was removed from the soil at the same time. Soil bound loosely to the roots was removed by shaking, and a brush was used to remove the rest of the soil bound to the roots. This soil was brought back to the laboratory and labeled as the tobacco rhizosphere soil, and the pH of the soil, organic carbon, alkaline hydrolysis nitrogen, phosphorus and available potassium were determined after air-drying and sieving [15].

Data Analysis

The data obtained from the experiment were analyzed using SPSS 9.3 with p< 0.05 as the threshold for significance. One–way variance analysis followed by LSD test was used to test for significant differences among treatments. And the figures were plotted using Excel 2003.

Results and Analysis

The Effects of Straw Biochar on Tobacco Agronomic Traits

Agronomic traits data obtained from the tobacco resettling stage and squaring stage (Table 1 and Table 2) showed that at the resettling stage, the height of T1 was the highest of all, and which was significantly different from that of T2 and T3. None of the treatments were significantly different from T0 with regard to the productive leaves. The maximal leaf area of T0 was significantly lower than that of T1, and higher than T3, but not different from T2. These data suggest that addition of a small amount of straw biochar (0.2 %) during the early growth stage promotes the tobacco growth, but addition of higher amounts of biochar (5 %) inhibits the tobacco growth.

At the squaring stage, there were no significant differences of tobacco height among T0, T1 and T2 treatments. But the tobacco height of T3 was significant lower than them. T1 had the maximum number of productive leaves, significantly higher than those in other treatment groups, which had no significant difference. T2 showed the maximum value of leaf area (including lower, middle and upper leaf), and which was significantly higher than other treatments. T1 was the second, although not significantly different from T0. While, T3 had the
smallest value of leaf area among all treatments. Thus, adding the moderate amount of biochar (0.2-1.0 \%) in soil contributes to the growth of tobacco, while higher content of biochar negatively affects the growth of tobacco.

Table 1. The main agronomic traits of tobacco at the resetting stage.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Height (cm)</th>
<th>Productive Leaves (slice)</th>
<th>Maximal Leaf Area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>21.00ab</td>
<td>10.67a</td>
<td>371.56b</td>
</tr>
<tr>
<td>T1</td>
<td>21.83a</td>
<td>10.00a</td>
<td>404.94a</td>
</tr>
<tr>
<td>T2</td>
<td>18.50bc</td>
<td>10.00a</td>
<td>382.13ab</td>
</tr>
<tr>
<td>T3</td>
<td>16.67c</td>
<td>9.67a</td>
<td>351.82c</td>
</tr>
</tbody>
</table>

Different lowercase alphabets in the same column indicate significant difference (p < 0.05).

Table 2. The main agronomic traits of tobacco at the squaring stage.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Height (cm)</th>
<th>Productive Leaves (slice)</th>
<th>Lower leaf Leaf Area (cm²)</th>
<th>Middle leaf Leaf Area (cm²)</th>
<th>upper leaf Leaf Area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>132.33a</td>
<td>24.67b</td>
<td>831.99b</td>
<td>1005.72ab</td>
<td>201.80b</td>
</tr>
<tr>
<td>T1</td>
<td>135.67a</td>
<td>26.00a</td>
<td>846.07b</td>
<td>997.61b</td>
<td>190.95b</td>
</tr>
<tr>
<td>T2</td>
<td>135.33a</td>
<td>24.33b</td>
<td>947.41a</td>
<td>1049.94a</td>
<td>249.52a</td>
</tr>
<tr>
<td>T3</td>
<td>117.33b</td>
<td>23.00bc</td>
<td>763.65bc</td>
<td>884.44c</td>
<td>201.85b</td>
</tr>
</tbody>
</table>

Different lowercase alphabets in the same column indicate significant difference (p < 0.05).

**Effects of Straw Biochar on Growth and Development of Tobacco Roots**

The growth of tobacco root system during the tobacco growth stages from the resetting stage to the mature stage (Fig. 1) showed that at the resetting stage, the root volume of tobacco was little, while at the vigorous growth stage, the root volume and taproot length in tobacco increased more quickly, with the taproot length reaching its maximum growth at this stage. From squaring stage to mature stage, the root volume of tobacco increased with the growth stage, while the length of the taproot and lateral roots (including the first and second order) tended to decline, which might associate with the increased number of lateral root and its vitality, that were resulted in the changes of metabolic after topping [16]. At the mature stage, taproot of tobacco became aging and meanwhile, the adventitious roots increased, which accounted for approximately 10 \%-30 \% of the total tobacco roots. During the early growth stage, there were no significant differences of root growth among the treatments, while towards the latter periods of growth, the biochar treatments, especially the T3 treatment increased the root volume, promoted the growth of first and second order lateral roots, and delayed the senility of the whole root system.
Effects of Straw Biochar on Tobacco Biomass

The biomass of different tobacco organs and the root-shoot ratio during tobacco growth stages (Fig. 2) showed that during the earlier stages, the values of biomass of both aboveground and underground organs were the lowest in the T3 treatment, and highest in T1. Towards the latter stage, the biomass of leaves, aboveground and underground organs in T1 and T2 treatments, was higher than those in T0. The biomass of different part of leaves and aboveground organs in T3 treatment was the lowest among all treatments, indicating that addition of larger amount of biochar restrains the growth of the aboveground organs, while it can promote the growth of the root system, producing a maximal increase in its underground biomass. Ma et al.[17] also concluded that biochar application could promote the growth of wheat, and significantly improved dry weight of wheat on the ground, but as the dosage was increased, the increase in dry weight of wheat was not significant.

The dynamics of the root-shoot ratio indicated that at the resetting stage, the root-shoot ratio of T0 was higher than that in other biochar treatments. And biochar had a gradual promoting effect on the growth of the root system after the vigorous growth stage. The root-shoot ratio of tobacco in T3 treatment was significantly higher than that in other treatments. Thus, biochar addition could regulate the root-shoot ratio. And the appropriate amount of biochar (0.2%–1%) addition can promote the growth of aboveground and underground organs of tobacco, while the growth of aboveground organs of tobacco is inhibited by higher quantities of biochar (5%).
Effects of Straw Biochar on Soil Nutrients

The results from the soil nutrients at tobacco mature stage (Table 3) showed that with the increase in the straw biochar amount added, the soil nutrients of pH, soil organic carbon, alkali-hydrolysable N, available P and available K were increased. There was no significant difference between T0 and T1, except for available K, while all the soil nutrients in T0, T2 and T3 were significantly different from each other. Straw biochar itself contains a certain amount of organic carbon and alkali metal ions after the straw pyrolysis process. Hence, soil pH and soil organic carbon are increased by biochar addition. Biochar also contains a certain amount of available nutrients, and has a special porous structure and surface functional groups that can absorb N, P, and K nutrient ions and reduce leaching loss in the soil. Some studies [18-20] also showed that biochar addition could improve the soil pH significantly under different soil types, and the organic matter of the soil after biochar application was significantly higher than that of the control soil. In addition, the porous structure and large specific surface area of biochar can effectively reduce the volatilization of ammonia in soil, enhance the adsorption of soil nutrients, reduce nutrient leaching, and aid phosphorus retention in the form of soluble available phosphorus [21]. Thus, straw biochar is a good soil conditioner in tobacco field, which can improve soil nutrients adsorption at appropriate level through both directly and indirectly effect.

Table 3. The soil nutrients in different treatments at tobacco mature period.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>pH</th>
<th>Soil Organic Carbon (g/kg)</th>
<th>Alkali-hydrolyzable Nitrogen (mg/kg)</th>
<th>Available P (mg/kg)</th>
<th>Rapidly Available K (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>6.38c</td>
<td>10.94c</td>
<td>92.18c</td>
<td>81.97c</td>
<td>695.49d</td>
</tr>
<tr>
<td>T1</td>
<td>6.56c</td>
<td>12.32bc</td>
<td>105.48c</td>
<td>87.40bc</td>
<td>994.16c</td>
</tr>
<tr>
<td>T2</td>
<td>7.12b</td>
<td>13.00b</td>
<td>124.09b</td>
<td>92.26b</td>
<td>1373.12b</td>
</tr>
<tr>
<td>T3</td>
<td>7.72a</td>
<td>43.92a</td>
<td>140.05a</td>
<td>118.88a</td>
<td>2352.77a</td>
</tr>
</tbody>
</table>
Summary

Based on the results, we concluded that the addition of suitable amount of biochar to soil (0.2-1.0%) contributed to the growth of tobacco, but inhibited its growth when higher amounts were added (5%). Moreover, different amounts of biochar application could promote the growth of the tobacco root system. The root-shoot ratio was highest and the recession process of lateral roots and the whole root system was delayed at later growth stage when biochar is added at 5%. We also concluded that soil pH, organic carbon and available soil nutrients increased with the increase amount of biochar addition. Consequently, the addition of appropriate amount of biochar (0.2-1.0%) not only promoted the growth of the aboveground and underground parts of tobacco, but also improved soil fertility in the tobacco pot experiment. However, the interaction between biochar and soil will be a long-term process, the influence of biochar application on the tobacco growth and soil fertility still needs further investigated with different soil types and in long-term field experiments.

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References


