Growth Performance, Nutrient Absorption of Tobacco and Soil Fertility after Straw Biochar Application

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Abstract

A Pot experiment was conducted to study the effect of straw biochar application on growth, nutrient absorption of flue-cured tobacco and soil fertility. The tobacco height, productive leaves and leaf area were all promoted by biochar application at appropriate levels (0.2–1.0%), while they were inhibited by high-level (5%) biochar application. Growth of the root system was promoted more extensively by biochar application at all levels tested than the aboveground organs, with 5% biochar addition resulting in the highest root-shoot ratio, which also delayed the senility of tobacco root system including lateral roots. The taproot length, lateral roots and root-shoot ratio of tobacco all increased at early growth stage but decreased at latter growth stage. The biochar had different effect on N, P and K concentrations of tobacco organs. Large amount of biochar addition (5%) decreased N and P contents, but significantly increased K content in tobacco organs. Moreover, the soil bulk density decreased, while an increase was observed in soil pH and soil nutritional indicators including, organic carbon, alkali-hydrolysable N, available P and K, with the soil nutrient level highest in the 5% biochar treatment. Our results induced that 0.2–1.0% levels of straw biochar application might be appropriate in the tobacco field. © 2016 Friends Science Publishers

Keywords: Pot experiment; Biomass; Root-shoot ratio; Soil nutrient

Introduction

As a large agricultural country, 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 (Zeng et al., 2007). This is not only a great waste of natural resources, but also a significant source of air pollution (Qu et al., 2012). 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 (Huang et al., 2013).

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) (Lehmann et al., 2006). 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 (Gerard et al., 2004). As a form of agricultural waste, straw poses universal problems, such as low utilization rate as fertilizer, traffic accident occurred on highway and environmental pollution caused by direct combustion. 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 (Oguntunde et al., 2008). The beneficial effect of biochar on the physical and chemical properties of soil also helps to maintain the balance of soil ecosystems, improve the soil’s ecological function, which has great significance in promoting crop growth and development (Mchenry, 2009).

Biochar is of great importance in increasing soil carbon storage, improving soil fertility, as well as maintaining the balance of soil ecosystems, and it could act as a kind of soil fertilizer or amendment to increase crop yield and plant growth by supplying and retaining nutrients. Many studies show that application of a certain amount of biochar in the field could increase crop yield and plant growth to different extents (Steiner et al., 2007; Major et al., 2010; Noguera et al., 2010; Ahmad et al., 2013).

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, 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

Description of Experiments

Pot experiments were conducted in the greenhouse of the "Qing Jiang Yuan" modern tobacco agriculture science and Technology Park in Enshi, Hubei province, in 2013. The soil used from arable layer of local tobacco field was typic dystrochrept. The physical and chemical properties of the soil were as follows: pH 6.9, soil organic matter 19.23 g kg⁻¹, alkali-hydrolysable nitrogen (N) 85.37 mg kg⁻¹, available phosphorus (P) 62.70 mg kg⁻¹ and available potassium (K) 318.67 mg kg⁻¹. The flue-cured 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, manufactured by the Nanjing Soil Research Institute, Chinese Academy of Sciences. Its physical and chemical properties were as follows: pH 9.20, total carbon content 630 g kg⁻¹, total nitrogen content 13.5 g kg⁻¹, ash content 140 g kg⁻¹, total phosphorus 4.50 g kg⁻¹, and total potassium 21.5 g kg⁻¹. Biochar was thoroughly mixed with the soil and fertilizer on a plastic film, and then sieved to 2-mm mesh. Following this, some gravel was placed at the bottom of the pot to enhance water permeability, after which the pot was filled with soil. Fifteen kilograms of dried 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 hm⁻², with N: P₂O₅:K₂O=1:1.5:3. All fertilizers were applied simultaneously as basal fertilizers.

Treatments

For the pot experiment we used a control and three treatments with straw biochar applied at three levels, each one repeated 15 times. The treatments were as follows:

- T0: Control, no biochar addition (0 g kg⁻¹ dry soil)
- T1: 0.2% biochar (2 g biochar kg⁻¹ dry soil)
- T2: 1.0% biochar (10 g biochar kg⁻¹ dry soil)
- T3: 5.0% biochar (50 g biochar kg⁻¹ dry soil)

The biochar amount added in these treatments was calculated by the soil density and the biochar yield of rice straw (Wang et al., 2013). That is, the amount of biochar added in T1 equaled 4500 kg km⁻² that was similar to the amount (15 t km-2) made by rice straw annually. T2 and T3 treatments were to simulate the soils after prolonged addition of biochar.

Sampling and Analyses

After transplanting, five pots per treatment were used to observe the growth and development and record the main agronomic traits indices of tobacco at the rosette stage and squaring stage. Leaf area was calculated as follows:

\[ \text{Leaf area} = \text{leaf width} \times \text{leaf length} \times \text{leaf area index} \]

The leaf area index value of 0.6345 was used for calculation (Suggs et al., 1960).

Three representative tobacco plants were selected at different development stages (rosette stage, vigorous growth stage, squaring stage and flat-topped stage); the entire root systems of these were dug out and rinsed thoroughly. Following this, the growth of the 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.

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 tobacco root, stalk and leaves in different treatment at flat-topped stage were sampled and measured the nitrogen, phosphorus and potassium concentration. At the mature stage of tobacco, the cutting-ring method was adopted to measure the soil bulk density. And further soil samples were brought back to the laboratory. The pH was measured in 1:2.5 soil-water mixture (Jackson, 1970). Soil organic matter content was measured by using modified Walkley-Black method (Nelson and Sommers, 1982) and alkaline hydrolysis nitrogen by modified Kjeldahl method (Bremner, 1965). Available phosphorus content of soil samples were analyzed as described by Olsen and Sommers (1982), and exchangeable potassium content of soil samples were analyzed by the method of Warncke and Brown (1998).

Data Analysis

The data obtained from the experiment were analyzed using SPSS 16.0. (SPSS Inc., Chicago, IL, USA) using P<0.05 as the threshold for significance. One-way analysis of variance (ANOVA) followed by LSD test was used to test for significant differences among treatments. And the figures in this study were plotted using Microsoft Excel 2003.

Results

The Tobacco Agronomic Traits

Agronomic traits data obtained from tobacco resettling
stage and squaring stage (Table 1 and Table 2) showed that at the rosette stage, the height of tobacco in T1 was the highest of all, and which was significantly different from that in T2 and T3. None of the treatments were significantly different from T0 with regard to the productive leaf. The maximal leaf area of T0 was significantly lower than that of T1, and higher than T3, but not different from T2. These data suggested that addition of a small amount of straw biochar (0.2%) during the early growth stage could promote 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 in T3 was the lowest of all. The productive leaf in T1 was more than those in other treatments. The maximum values of leaf area (including lower, middle and upper leaf) were found in T2, and which was significantly higher than other treatments. Meanwhile T3 had the smallest value of leaf area of lower or middle leaf among all treatments. Thus, adding moderate amount of biochar (0.2–1.0%) in soil could contribute to the growth of tobacco, while higher content of biochar (5%) inhibit the growth of tobacco.

**The Growth and Development of Tobacco Roots**

The growth of tobacco root system during the tobacco growth stages from the rosette stage to the mature stage (Fig. 1) showed that at the rosette 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 stage. At the mature stage, taproot became aging and meanwhile, the adventitious roots increased, which accounted for 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.

**The Tobacco Biomass and Root-shoot Ratio**

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

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

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

Data from Fig. 3 demonstrated the effects of straw biochar on NPK uptake by tobacco at flat-topped stage. Straw biochar addition changed the NPK concentrations in the organs and tissues of tobacco compared to the control. The N concentration in tobacco leaves was significantly higher than that in root and stalk. It was increased or remained the same and then decreased with the amount of biochar. And N concentration in root, stalk and leaves in T1 treatment were increased by 5.18%, 0.81% and 6.02%, and in T3 treatment reduced by 7.61%, 15.21% and 10.49% individually, compared to the T0 treatment. As to the P concentration in tobacco organs, the similar conclusion was also found.
But the K concentration in different tobacco organs were all increased or remained constant with the amount of straw biochar, and the highest values were found in T3 treatment, that the K concentration in root, stalk and leaves in T3 was increased by 21.56%, 29.78% and 37.27% individually compared to the control. And the K concentration in tobacco leaves and stalk were significantly higher than that in root among all treatments. So, the application of biochar had different effect on the N, P, and K nutrients of tobacco organs, that small amount of biochar addition (0.2%) could increase N and P contents slightly in the tobacco. Large amount of biochar addition (5%) could decrease them, but significantly increase K content ($p < 0.05$) in the tobacco organs.

**The Soil Nutrients after Straw Biochar Addition**

The results from the soil physical and chemical properties at tobacco mature stage (Table 3) showed that biochar addition could reduce the soil bulk density to some extent. No significant difference of bulk density was observed between treatments T1 and T0, but treatments T2 and T3 were significantly lower than T0. Furthermore, with the increasing amount of straw biochar addition, the soil...
Table 3: Soil physical and chemical properties of different treatments at tobacco mature stage

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Bulk Density (g cm⁻³)</th>
<th>pH</th>
<th>Organic Carbon (g kg⁻¹)</th>
<th>Alkali-hydrolysable Nitrogen (mg kg⁻¹)</th>
<th>Available P (mg kg⁻¹)</th>
<th>Available K (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>1.29a</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>1.25ab</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>1.18b</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>1.07c</td>
<td>7.72a</td>
<td>43.92a</td>
<td>140.05a</td>
<td>118.88a</td>
<td>2352.77a</td>
</tr>
</tbody>
</table>

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

Fig. 3: The nutrients adsorption of tobacco at flat-topped stage

Discussion

Application of different amounts of biochar under different soil and crop conditions has different influences on crop growth and development. A greenhouse experiment showed that application of 20% biochar combined with 0.7% humic acid could promote the growth and nutrition of ornamental plant Calathea insignis (Zhang et al., 2014). Our study showed that suitable amounts of biochar (0.2%–1%) promoted the growth and development of aboveground and underground organs of tobacco, while higher amounts of biochar (5%) inhibited the shoot growth but promoted the root growth of tobacco. A study about the effect of biochar on maize growth and development also led to the similar conclusion that, the growth and physiology of maize was improved at 1.0% biochar level as compared to other biochar levels (0.5 and 1.5%) (Ahmad et al., 2015). And a substantial increase was found in plant height, shoot dry weight and maize yield with biochar addition compared to the untreated control (Abid et al., 2014). On the growth of rice, biochar application can increase the plant height, number of tillers and number of panicles compared to controls (Maftuah and Indrayati, 2013). And the rice root volume, fresh weight, root-shoot ratio, total absorption area and active absorption area were all significantly improved after the biochar addition of 1–2% level, and the senescence of root system was delayed to a certain extent for the enhanced root physiological functions (Zhang et al., 2013).

Biochar application could also affect the nutrients uptake of crops. It was found that the phosphorus and nitrogen uptake in wheat shoots were significantly greater for a low application rate of biochar (Joseph et al., 2015; Lu et al., 2015). And biochar application positively affected above-ground biomass production and decreased in plant tissue nutrient concentrations (N and P) in maize (Rogovska et al., 2014). Furthermore, the crop growth, biomass and yield could increase greater when biochar was applied with chemical fertilizers (Solaiman et al., 2010). So, the application of straw biochar to soil has been shown to improve crop growth and yield, which might be related to nutrient uptake by enhancing soil properties.

Biochar is recognized as offering a number of benefits for soil fertility, which are related to its high porous structure, carbon sequestration and cation retention (Silber et al., 2010). And the conclusion that straw biochar can
improve soil physical, chemical and biological properties have been confirmed by many researchers (Lehmann et al., 2011; Huang et al., 2013; Lone et al., 2015). In our study, the straw biochar application with 1% or 5% level both significantly decreased soil bulk density compared with the control. Oguntunde et al. (2008) demonstrated that application of biochar could reduce soil bulk density by an average of 9% and improve soil total porosity from 45.7% to 50.6%. Laird et al. (2010) also showed that biochar application significantly decreased soil bulk density compared to control soil. Therefore, the straw biochar application could provide a good soil environment for plant growth. Furthermore, soil pH, organic carbon and its related nutrients were all increased by the straw biochar addition in the pot experiment. The biochar could increase soil pH through the hydrolysis of alkaline metal ion, which produces OH into the soil from the ash of biochar (Glasier et al., 2002). The organic matter of the soil after biochar application was significantly higher than that of the control soil. The carbon content and porosity in biochar is very high, which can improve the soil carbon content directly, but also improve soil active organic carbon and soil microbial activities by creating new habitats and changing the soil micro-environment for soil microorganisms (Lehmann et al., 2011). Thus, straw biochar is a good soil conditioner in tobacco field, which can improve tobacco growth and nutrients adsorption at appropriate level through both directly and indirectly effect.

In conclusion, 0.2 growth. 5% level of biochar decreased it, but increased the root growth and root-shoot ratio. Furthermore, 5% level of biochar decreased N and P contents, but increased K content significantly in tobacco organs and most of nutrients in the spot soil. So, the amount of straw biochar application should be determined considering its integrated impact on tobacco growth and soil fertility in tobacco planting area.

Acknowledgements

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