# EFFECTS OF DIFFERENT BIOCHAR-BASED FERTILIZERS ON THE BIOLOGICAL PROPERTIES AND ECONOMIC BENEFITS OF POD PEPPER (*Capsicum annuum var. frutescens* L.)

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**Abstract.** Biochar-based fertilizer has been widely proposed as an amendment to improve soil quality and crop productivity, while few have explored the effects of biochar-based fertilizer on fruit quality and economic benefits. Two field experiments were conducted to investigate the effects of different biochar-based fertilizers on pod pepper yield, fruit quality, nutrient uptake and utilization, and economic benefits in Guizhou Province, China in 2018 and 2019. Results indicated that the supply of biochar-based fertilizer could significantly increase the yield and fruit quality compared to traditional fertilization practice (TFP). Furthermore, the accumulation of nitrogen (N), phosphorus (P) and potassium (K), the fertilization agronomic efficiency (AE) and recovery efficiency (RE) all significantly increased. After the deduction of the corresponding fertilizer cost, the application of biochar-based fertilizer also significantly increased the net proceeds except for the biochar-based fertilizer 1 (B1) treatment.
**Keywords:** *pod pepper, nitrate, Vitamin C, nutrient accumulation, fertilizer utilization*

## Introduction

China is one of the largest agricultural countries in the world. With an average annual increase rate of 4% for the crop straw production in China in the past decades, the country has also become one of the countries with the most abundant of straw resources in the world (Zeng et al., 2007; Hong et al., 2016). In addition to being used as a bioenergy source, livestock forage, culture medium and crop straws in China have long been removed from the field, which has led to a large sum of straw nutrient loss (Owaid et al., 2015; Yin et al., 2018). What is more, the proportion of crop straw returning to farmland in China (15%) is unsatisfactory compared to the developed countries (70% in United States, Europe) (Wang et al., 2016). Realizing the efficient use of crop straw has become an important task but the lack of research poses problems for the current green agricultural development of China.

Biochar is the stable solid biomass which has been pyrolyzed in a low oxygen environment (Laird et al., 2009), and has the potential ability to improve the soil physical properties, electrical conductivity, cation exchange capacity, fertility and crop productivity (Graber et al., 2010; Smith et al., 2010; Zhang et al., 2010, 2013; Liu et al., 2014; Gul et al., 2015; Shi et al., 2018). Many studies have also been conducted around the world to investigate the effects of biochar application on crop yields because of its role in sequestering carbon and enhancing nutrients efficiency in soil. Jin et al. (2019) reported that the application of biochar significantly increased the rapeseed yield and yield components. Graber et al. (2010) reported that biochar application significantly promoted the growth of pepper and tomato and increased the yield. Akhtar et al. (2014)


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found that the yield and quality of tomato was significantly enhanced for the supply of biochar. Gamareldawla et al. (2017) reported that the supply of biochar amendment promoted the growth of tomato and increased the yield. Agegnehu et al. (2016) reported that the combined use of biochar and nitrogen significantly increased the barley yield. Liu et al. (2017) reported that the application of biochar significantly increased the yield of maize/soybean and maize/peanut systems. Saxena et al. (2013) have shown that the supply of biochar not only increased the yield of French beans. The uptake of nitrogen, phosphorus and potassium was also found to be increased with the supply of biochar in *Lactuca sativa* (Nigussie et al., 2012).

Pod pepper (*Capsicum annuum var. frutescens* L.) is an important characteristic cash crop in Guizhou province, China. However, the yield and fruit quality of pod pepper was severely restricted by the long-term continuous cropping, low input of organic fertilizer, imbalance of soil C/N and degraded soil fertility in recent years. There have been conducted a lot of studies on biochar, however, most of them were focused on the yield responses and soil physical properties while the mechanisms affected by biochar remain poorly understood. Therefore, the objectives of this study were: (1) to investigate the effects of different biochar-based fertilizers on pod pepper yield and fruit quality; (2) to calculate the effects of different biochar-based fertilizers on fertilizer efficiencies; (3) to evaluate the economic benefits of applying biochar-based fertilizers on pod pepper.

## Materials and methods

### *Experimental site*

The field trails were conducted at Shiban Town (27°31’29” N, 106°43’50” E) in Guizhou Province, China in 2018 and 2019. The long-term average annual rainfall at Shiban Town is 1150 mm. The long-term average temperature is 23.6 °C. About 280 days in the year are frost-free. *Figure 1* showed the field experiment in 2018. The previous crop was pod pepper. The field was fallow in winter. The soil chemical properties of the top 20 cm were as follows: pH 6.0, organic matter 26.8 g·kg$^{-1}$, total N 2.2 g·kg$^{-1}$, available P 48.6 mg·kg$^{-1}$, exchangeable K 175.0 mg·kg$^{-1}$.

***Figure 1.*** *Photo of the field experiment*


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### *Experimental design and management*

Urea (N 46%), compound fertilizer (N-$P_2O_5$-$K_2O$ 15-15-15), biochar-based fertilizer 1 (N-$P_2O_5$-$K_2O$ 12-6-10.8, carbon 10%), biochar-based fertilizer 2 (N-$P_2O_5$-$K_2O$ 12-6-10.8, carbon 20%), biochar-based fertilizer 3 (N-$P_2O_5$-$K_2O$ 12-6-10.8, carbon 30%) and biochar-based fertilizer 4 (N-$P_2O_5$-$K_2O$ 12-6-10.8, carbon 40%) were used (*Table 1*). The biochar was corn straw carbon, and the carbonization temperature was 450 ℃. The properties of the biochar were as follows: pH 7.95, organic carbon 473.61 $g \cdot kg^{-1}$, total N 8.04 $g \cdot kg^{-1}$, total P 1.88 $g \cdot kg^{-1}$, total K 47.53 $g \cdot kg^{-1}$. The pod pepper variety was Yanjiao 425 (Chongqing Keguang co., LTD). Urea (N 46%), ammonium dihydrogen phosphate (N-$P_2O_5$ 12-60) and potassium sulfate ($K_2O$ 52%) were used. The biochar-based fertilizer was made with a flat grinding extrusion granulator (SKJ-120).

***Table 1.*** *The percentage composition of the applied biochar-based fertilizer*

| Biochar-based fertilizer | Urea | Diammonium hydrogen phosphate | Potassium sulphate | Corn stalk biochar | Bentonite | Binder |
|---|---|---|---|---|---|---|
| **B1** | 23.5 | 10 | 20.8 | 10.0 | 30.7 | 5.0 |
| **B2** | 23.5 | 10 | 20.8 | 20.0 | 20.7 | 5.0 |
| **B3** | 23.5 | 10 | 20.8 | 30.0 | 10.7 | 5.0 |
| **B4** | 23.5 | 10 | 20.8 | 40.0 | 0.7 | 5.0 |

Seedlings were raised in the seedbed on 20th and 26th Mar and transplanted on 22nd and 29th Apr in 2018 and 2019, respectively. The planting density was $5.2 \times 10^4$ $ha^{-1}$ (with a plant spacing of 30 cm, row spacing of 60 cm).

A completely randomized block design with six treatments and three replications was used. The six treatments were: no fertilizer (CK), traditional fertilization practice (TFP), biochar-based fertilizer (carbon 10% (B1), carbon 20% (B2), carbon 30% (B3), carbon 40% (B4)). Compound fertilizer and biochar-based fertilizer were used as base fertilizer and turned over the soil after the fertilization. The specific fertilizer amounts were shown in *Table 2*. The plot area was 20 $m^2$ (4.0 m×5.0 m). All treatments received the same fungicide, insecticide and herbicide treatments, and no major diseases, pests or weeds were present during the growing seasons.

***Table 2.*** *Fertilizer amounts of different treatments*

| Treatments | Basal dressing fertilizer ($kg \cdot ha^{-1}$) | | First dressing fertilizer ($kg \cdot ha^{-1}$) | Second dressing fertilizer ($kg \cdot ha^{-1}$) |
|---|---|---|---|---|
| | Compound fertilizer | Biological carbon fertilizer | Urea | Urea |
| **CK** | — | — | — | — |
| **TFP** | 1500 | — | 300 | 300 |
| **B1** | — | 2550 | — | — |
| **B2** | — | 2550 | — | — |
| **B3** | — | 2550 | — | — |
| **B4** | — | 2550 | — | — |


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### *Sampling and measurement*

Soil samples (0-20 cm) were collected from 10 randomly selected spots of the main experimental area one day before transplanting. The soil samples were composited and air-dried, ground and passed through 1 mm and 0.149 mm sieves for the determination of soil physicochemical characteristics. The soil chemical properties like pH, organic matter, total N, available P, and exchangeable K were determined following the procedures of Bao (2000). Soil pH was measured in a 1:2.5 (soil: water ratio, w/v) extraction with a pH meter (FE20K, Mettler Toledo, Switzerland), organic matter was determined by wet combustion method, total N was determined using Kjeldahl method, available P was determined by sodium bicarbonate method, exchangeable K was extracted with ammonium acetate and boiling nitric acid, and determined with a flame photometer (FP640, Jingke, Shanghai, China).

Six plants were sampled before the final harvest, which were used to test the plant nutrition and fruit quality. The plant was divided into three parts: straw, leaf and fruit, which were heated to a constant weight at 60 °C after heating at 105 °C for 30 minutes. All dried samples were ground and passed through a 0.25 mm sieve and digested with a mixture of concentrated $H_2SO_4$ and $H_2O_2$ (Wolf, 1982) to determine N, P and K concentrations. The N concentration was determined with a continuous flow analyzer (AA3, Seal Analytical Inc., Southampton, UK), P and K concentration was determined with an ICP-OES (optic emission spectroscopy with inductively coupled plasma, Longjumeau, HORIBA Jobin Ibon S.A.S., France). The uptake of N, P and K were calculated based on the dry mass and element concentration. At the same time, some fresh fruit samples were used to determine the quality indices. 0.1 g sample was mixed with nitrate-free, activated charcoal in a ratio of 1:2. The nitrate was extracted into 20 ml of distilled water and determined using Szechrome NAS (Nambiar et al., 1988). The Vitamin C (Vc) concentration was determined by high performance liquid chromatography (HPLC) (Plaza et al., 2006). The reducing sugar concentration was according to Somogyi’s method (Nii, 1997). The free amino acid concentration was determined according to Curtis et al. (2009). 0.5 g sample was weighed into a vial. 10 ml 0.01 M HCl was added into the vial and stirred for 15 min. After a stand of 15 min, 1.5 ml sample was removed and centrifuged at 7200 for 15 min. 100 µL of the supernatant was then derivatized using the EZ-Faast amino acid derivatization technique for gas chromatography and mass spectrometry (GC-MS) (Phenomenex, Torrance, CA) The final yield was an accumulation of whole plot based on three batches of harvest.

### *Calculations and statistical analysis*

$$\text{Nutrient accumulation (kg ha}^{-1}\text{)} = \text{nutrient concentration (\%)} \times \text{dry mass (kg ha}^{-1}\text{)} / 100 \quad \text{(Eq.1)}$$

$$\text{Agronomic efficiency (AE, kg kg}^{-1}\text{)} = \text{(yield of the fertilized plot - yield of the no fertilizer plot) / applied nutrient rate} \quad \text{(Eq.2)}$$

$$\text{Recovery efficiency (RE, \%)} = \text{(total nutrient uptake of fertilized plot – total nutrient uptake of no fertilizer plot) / applied nutrient rate} \times 100\% \quad \text{(Eq.3)}$$


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The yield and nutrient uptake in the upper formulas were calculated according to dry mass.

$$\text{Output value (USD ha}^{-1}\text{) = fresh weight of pod pepper (kg ha}^{-1}\text{)} \times \text{unit price (USD kg}^{-1}\text{)} \quad \text{(Eq.4)}$$

$$\text{Increased output value (USD ha}^{-1}\text{) = output value with fertilizer - output value without fertilizer} \quad \text{(Eq.5)}$$

$$\text{Net proceeds (USD ha}^{-1}\text{) = output value with fertilizer - fertilizer inputs} \quad \text{(Eq.6)}$$

In the calculation of economic benefits, the unit price of fresh pod pepper was 0.2922 USD kg$^{-1}$, the compound fertilizer, urea, ammonium dihydrogen phosphate, potassium sulphate, corn stalk biochar, bentonite and binder were 0.3287, 0.2922, 0.4091, 0.5844, 0.2776, 0.0438 and 0.2922 USD kg$^{-1}$, respectively. Considering the cost of labor, water, electricity and so on, the unit price of B1, B2, B3 and B4 was 0.4821, 0.5055, 0.5289, 0.5522 USD kg$^{-1}$, respectively.

A statistical analysis was performed using SPSS 18.0 (SPSS Inc., Chicago, IL, USA). The data means were compared using the LSD test at the 5%. The figures were conducted with Origin 8.0 (Origin Lab Corporation, USA).

## Results

### *Yield*

Effects of different treatments on yield of pod pepper were shown in *Fig. 2*. The application of fertilizer (traditional fertilization practice (TFP), and biochar-based fertilizer) significantly increased the fresh and dry pod pepper weight than that of no fertilizer treatment (CK), which was increased by 8815 and 2129 kg·ha$^{-1}$ in 2018, and 8129 and 2387 kg·ha$^{-1}$ in 2019 on average. Compared to the TFP treatment, the fresh pod pepper was increased by 1192-4142 kg·ha$^{-1}$ and 2104-5733 kg·ha$^{-1}$ in 2018 and 2019 for the supply of biochar-based fertilizer, the increase rate was 7.6-24.4% and 15.0-40.8%, respectively. The treatment of biochar-based fertilizer 3 (B3) showed the highest fresh pod pepper weight in two years, which was 19930 and 19588 kg·ha$^{-1}$. The yield of dry pod pepper was similar to that of fresh. Compared to the TFP treatment, the dry pod pepper was increased by 409-1018 kg ha$^{-1}$ and 441-1482 kg ha$^{-1}$ in 2018 and 2019 for the supply of biochar-based fertilizer, the increase rate was 10.9-27.1% and 15.1-50.8%, respectively. The treatment of B3 showed the highest dry pod pepper weight with 4776 and 4398 kg·ha$^{-1}$ in 2018 and 2019, which was significantly higher than that of TFP.

### *Fruit quality*

Various parameters of fruit quality are presented in *Table 3*. The nitrate and Vitamin C (Vc) concentration of fresh pod pepper were significantly increased for the application of biochar-based fertilizer, while that of reducing sugar and free amino acid concentration had no significant effects. Compared to the TFP treatment, the nitrate concentration of fresh pod pepper was decreased by 0.1-4.2% and 11.5-23.1% for the


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application of biochar-based fertilizer. The fresh pod pepper of B3 treatment showed the minimum nitrate concentration in both two years. Compared to the TFP treatment, the Vc concentration of fresh pod pepper was increased by 2.0-14.5% and 0.7-15.4% in 2018 and 2019 for the application of biochar-based fertilizer. The fresh pod pepper of B3 treatment showed the maximum concentration of Vc in both two years. The reducing sugar and free amino acid showed no significant differences between different treatments.

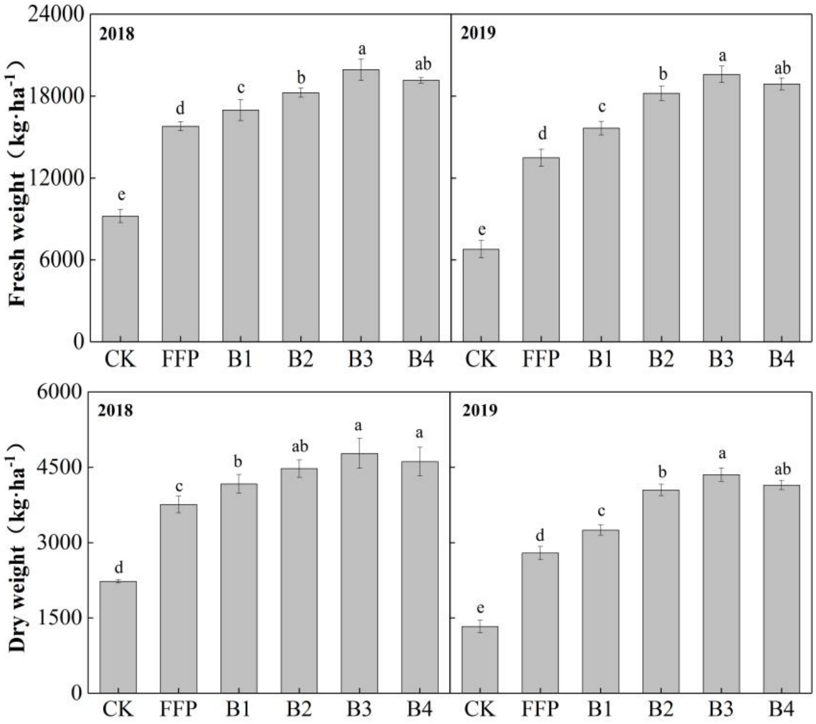


***Figure 2.*** *Effects of different treatments on fresh and dry yield of pod pepper. Different letters indicate significant indicate difference at 5% level. The same as below. Different letters in the same column means significant difference at 5% level*

***Table 3.*** *Effects of different treatments on quality of fresh pod pepper*

| Year | Treatments | Nitrate ($mg \cdot kg^{-1}$) | Vc ($mg \cdot 100\ g^{-1}$) | Reducing sugar ($g \cdot kg^{-1}$) | Free amino acid ($g \cdot kg^{-1}$) |
|---|---|---|---|---|---|
| 2018 | CK | 90.4±1.4 bc | 87.2±0.3 f | 24.3±1.4 a | 5.8±0.1 a |
| | TFP | 92.9±0.4 a | 90.2±0.3 e | 23.4±0.2 a | 5.8±0.1 a |
| | B1 | 92.8±1.2 a | 92.0±0.3 d | 23.7±0.5 a | 5.7±0.2 a |
| | B2 | 90.7±0.7 b | 93.7±0.2 c | 23.5±0.9 a | 5.6±0.1 a |
| | B3 | 89.0±0.2 c | 103.3±0.4 a | 22.8±1.8 a | 5.8±0.2 a |
| | B4 | 91.2±1.3 ab | 94.2±0.1 b | 23.3±0.8 a | 5.8±0.1 a |
| 2019 | CK | 76.5±0.2 b | 72.1±0.4 e | 26.8±0.4 a | 5.9±0.2 a |
| | TFP | 86.9±0.8 a | 85.3±0.4 d | 26.5±0.4 a | 5.9±0.1 a |
| | B1 | 76.9±0.9 b | 85.9±0.3 d | 27.0±0.7 a | 5.9±0.2 a |
| | B2 | 75.0±0.4 c | 93.0±0.7 c | 28.1±0.6 a | 5.8±0.1 a |
| | B3 | 72.0±0.4 d | 98.4±0.4 a | 27.6±0.5 a | 5.9±0.1 a |
| | B4 | 66.8±0.5 e | 94.8±0.6 b | 27.1±0.6 a | 5.9±0.1 a |

Note: Different letters in the same column means significant difference at 5% level


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### *Accumulation of nitrogen, phosphorous and potassium*

The accumulation of N, P and K was shown in *Fig. 3*. The application of fertilizer significantly increased the N, P and K accumulation rates than that of CK, the average increase rate was 151.5%, 109.7% and 134.0% in 2018, 201.9%, 243.5% and 184.1% in 2019, respectively. Compared to the TFP treatment, the N, P and K accumulation was increased by 19.0-34.8%, 9.4-28.3% and 28.4-51.7% in 2018, and 6.7-38.9%, 15.0-55.0% and 20.4-60.0% in 2019 for the supply of biochar-based fertilizer. The treatment of B3 showed the highest N, P and K accumulation rates in both two years, which was 263.3, 12.9 and 263.2 kg·ha$^{-1}$ in 2018 and 231.7, 11.0 and 255.1 kg·ha$^{-1}$ in 2019, respectively.

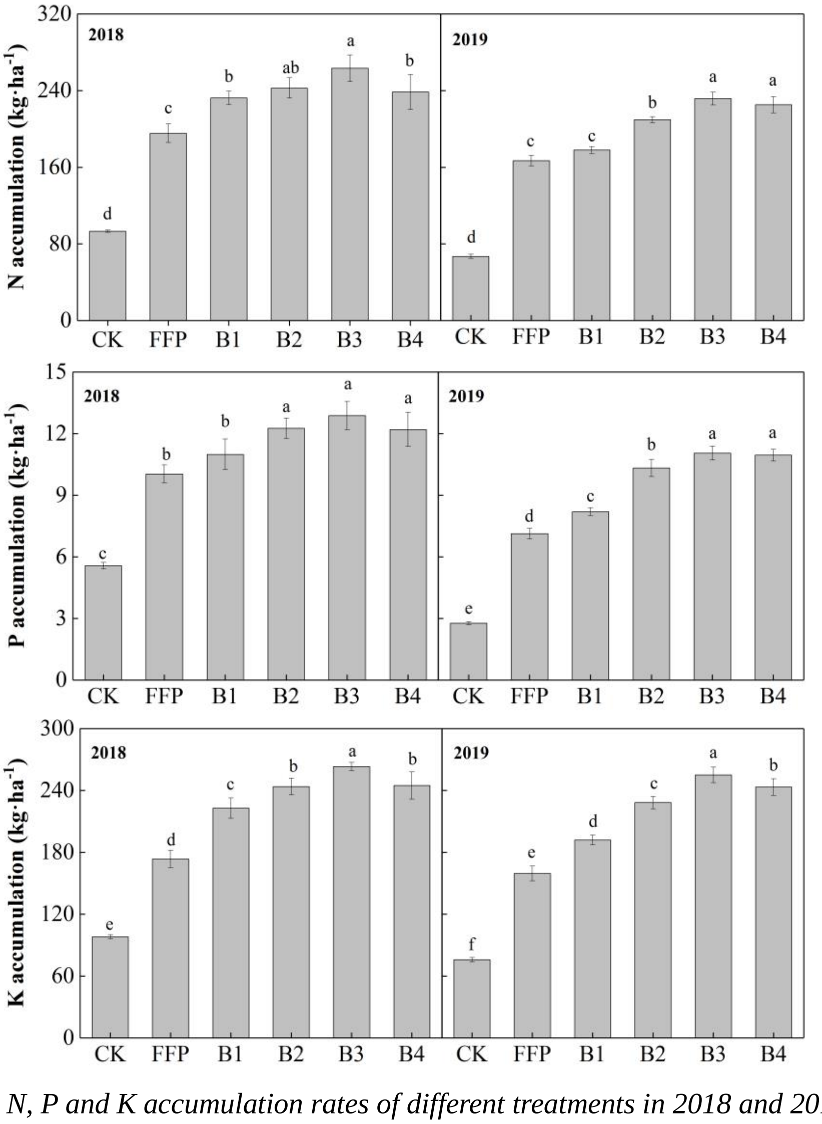


***Figure 3.*** *The N, P and K accumulation rates of different treatments in 2018 and 2019. Different letters in the same column means significant difference at 5% level*

### *Efficiency of fertilizer*

The agronomic efficiency (AE) and recovery efficiency (RE, %) was shown in *Table 4*. Compared to the TFP treatment, the AE of N, P and K was increased by


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93.4-166.8%, 73.7-139.5% and 3.1-33.1%, respectively for the supply of biochar-based fertilizer in 2018, and that was increased by 116.4-212.7%, 94.6-181.2% and 8.1-56.0% respectively in 2019. The treatment of B3 showed the highest AE of N, P and K in both years, which was 35.1, 70.1 and 39.0 kg·kg$^{-1}$ in 2018, and 41.9, 83.8 and 46.5 kg·kg$^{-1}$ in 2019, respectively. Compared to the TFP treatment, the RE of N P and K in 2018 was increased by 24.8-34.9%, 3.9-6.7% and 14.2-31.9%, and that was increased by 82.4-170.4%, 84.1-97.7% and 13.4-52.7% in 2019, respectively. The treatment of B3 showed the highest RE of N, P and K in both years, which was 54.8%, 11.9% and 75.2% in 2018, and 53.8%, 12.4% and 78.4% in 2019, respectively.

***Table 4.*** *Fertilizer utilization of different treatments*

| Year | Treatments | AE（kg·kg$^{-1}$） | | | RE（%） | | |
|---|---|---|---|---|---|---|---|
| | | **N** | **P** | **K** | **N** | **P** | **K** |
| **2018** | **CK** | — | — | — | — | — | — |
| | **TFP** | 13.1±1.4 d | 29.3±3.2 d | 29.3±3.2 cd | 19.9±2.1 c | 5.2±0.5 c | 40.4±4.4 d |
| | **B1** | 25.4±1.8 c | 50.8±3.6 c | 30.2±2.0 d | 44.7±2.5 b | 9.1±1.3 b | 54.6±5.1 c |
| | **B2** | 29.6±0.7 b | 59.1±1.5 b | 32.9±0.8 bc | 48.0±3.2 ab | 11.0±0.7 ab | 63.7±3.7 b |
| | **B3** | 35.1±1.3 a | 70.1±2.6 a | 39.0±1.5 a | 54.8±4.4 a | 11.9±1.0 a | 72.2±2.0 a |
| | **B4** | 32.5±1.9 a | 65.0±3.9 a | 36.1±2.2 ab | 46.7±5.7 ab | 10.9±1.3 ab | 64.2±6.1 ab |
| **2019** | **CK** | — | — | — | — | — | — |
| | **TFP** | 13.4±1.4 c | 29.8±3.3 c | 29.8±3.3 c | 19.9±1.5 d | 4.4±0.2 d | 44.8±2.9 d |
| | **B1** | 29.0±2.8 b | 58.0±4.9 b | 32.2±2.7 b | 36.3±1.7 c | 8.1±0.2 c | 50.8±1.4 c |
| | **B2** | 37.3±1.2 a | 74.7±2.4 a | 41.5±1.3 a | 46.6±0.9 b | 11.3±0.5 b | 66.7±2.6 b |
| | **B3** | 41.9±4.1 a | 83.8±8.1 a | 46.5±4.5 a | 53.8±2.2 a | 12.4±0.6 a | 78.4±4.2 a |
| | **B4** | 39.6±2.9 a | 79.2±5.7 a | 44.0±3.2 a | 51.7±2.5 a | 12.2±0.5 a | 73.3±4.3 a |

Different letters in the same column means significant difference at 5% level

## *Economic benefits*

Compared to the TFP treatment, the output value was increased by 348.3-1210.2 and 635.2-1786.7 USD·ha$^{-1}$ in 2018 and 2019 for the supply of biochar-based fertilizer, the increase rate was 18.1-62.9% and 16.1-45.4%, respectively (*Table 5*). The treatment of B3 showed the highest net proceeds of all treatments in both years.

***Table 5.*** *Effects of different treatments on economic benefits*

| Year | Treatments | Output value (USD·ha$^{-1}$) | Output value with fertilizer (USD·ha$^{-1}$) | Fertilizer inputs (USD·ha$^{-1}$) | Net proceeds (USD·ha$^{-1}$) |
|---|---|---|---|---|---|
| **2018** | **CK** | 2688.8±115.9 e | — | — | — |
| | **TFP** | 4613.0±98.0 d | 1924.2±210.8 d | 668.4 | 1255.8±210.8 bc |
| | **B1** | 4961.3±224.5 c | 2272.4±163.3 c | 1230.2 | 1042.2±163.3 c |
| | **B2** | 5331.9±98.2 b | 2643.2±68.4 b | 1289.8 | 1353.3±68.4 b |
| | **B3** | 5823.2±230.8 a | 3134.5±119.6 a | 1349.5 | 1785.0±119.6 a |
| | **B4** | 5593.3±57.7 ab | 2904.5±173.6 ab | 1409.1 | 1495.4±173.6 b |
| **2019** | **CK** | 1978.7±187.4 e | — | — | — |
| | **TFP** | 3936.6±182.3 d | 1958.0±218.6 d | 668.4 | 1289.6±218.6 c |
| | **B1** | 4572.0±144.3 c | 2593.2±221.6 c | 1230.2 | 1363.0±221.6 c |
| | **B2** | 5316.1±151.5 b | 3337.6±108.4 b | 1289.8 | 2047.8±108.4 b |
| | **B3** | 5723.3±175.9 a | 3744.6±71.1 a | 1349.5 | 2395.1±71.1 a |
| | **B4** | 5518.2±125.8 ab | 3539.7±112.8 b | 1409.1 | 2130.6±112.8 b |

Different letters in the same column means significant difference at 5% level


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## Discussion

Biochar has been used as an amendment to improve the soil fertility and increase crop yield. The results of this study are similar to those of previous studies that the supply of biochar-based fertilizer significantly increased the plant growth, carbon storage and crop yield. Compared to the TFP treatment, the fresh and dry mass of pod pepper was increased for the supply of biochar-based fertilizer. Gathorne-Hardy et al. (2009) reported that the application of biochar combined with N fertilizer increased the grain yield of spring barley by 30% compared to N fertilizer only. Zhu et al. (2015) reported that the combined use of biochar and inorganic fertilizer could increase maize biomass by 2.7-3.5 times relative to the inorganic fertilizer alone. In this research, the supply of biochar increased the dry pod pepper by 40.8% and 50.8%, respectively. Several studies have been conducted to account for the mechanisms of biochar. The supply of biochar could increase the leaf photosynthetic and transpiration rates and some other physiological properties (Kammann et al., 2011; Wang et al., 2014). The application of biochar increased the total net soil surface area, soil aeration and water retention (Chan et al., 2007; Kolb et al., 2009). The supply of biochar has been shown to change the rate of N cycling and reduce the N losses from soil, which was considered closely related to its highly porous structure, large surface area and strong ion exchange capacity (Glaser et al., 2001; Clough and Condron, 2010; Huang et al., 2014). However, elevating the C/N ratio causes the threat of N immobilization (Lehmann et al., 2003). The responses of root development to the supply of biochar were associated with soil conditions and plant types, as well as to interactions between the roots and surrounding soil (Prendergast-Miller et al., 2014). It was reported that the supply of biochar could provide abundant nutrients and then stimulate root development (Abiven et al., 2015). The supply of biochar also stimulated root growth, like the root biomass, root length and root tips (Makoto et al., 2010; Joseph et al., 2010; Solaiman et al., 2012). The improvement in fruit quality also could be explained by the influence of biochar-based fertilizer on promoting the development of root to deeper soil layers (Gamareldawla et al., 2017).

The supply of biochar-based fertilizer significantly improved the fruit quality and fertilizer efficiency. The nitrate concentration was decreased while the Vc concentration was increased, respectively. Compared to the TFP treatment, the AE and RE were also significantly increased for the supply of biochar-based fertilizer. The results in this study showed that the maximum increase rate of AE for N, P and K was significantly increased by 166.8%, 139.5% and 33.1%, respectively for the supply of biochar-based fertilizer, and the maximum increase rate of RE for N, P and K was significantly increased by 54.8%, 11.9% and 75.2%, respectively. Biochar has been reported to influence N dynamics by altering the rate of transformation process (Clough and Condron, 2010; Clough et al., 2013). Singh et al. (2010) reported that the application of biochar could reduce the N losses from soil in terms of $N_2O$ emission and $NH_3$ volatilization. Uzoma et al. (2011) reported that the nutrient uptake was increased due to the addition of biochar. Nigussie et al. (2012) also found that the supply of biochar could increase the uptake of N, P and K in *Lactuca sativa*.

Economic benefit is one of the most important attributes of farmland ecosystem, which is also an index for farmers to increase production and income. The results indicated that the net proceeds were significantly increased for the supply of biochar-based fertilizer in both years. It is worth noting that the net proceeds of B1 was 213.6 USD·ha$^{-1}$ less than that of TFP in 2018, even though the pod pepper yield of B1 was


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significantly higher than that of TFP. The premise of large-scale application of biochar is the economic feasibility of biochar application. However, most of the current studies focused on the plant and environment effects of applying biochar-based fertilizer, and little attention had been paid to the economic benefits. Due to the large amount of biochar applied in the early stage and the high price of biochar, the input cost of biochar is too high, and the benefit is relatively slow. In this study, the combined use of biochar and inorganic fertilizer significantly increased the pod pepper yield and economic benefit. In this study, the application rate of 2550 kg $ha^{-1}$ biochar-based fertilizer (carbon 30%) is recommended as the most appropriate in the cultivation of pod pepper in Guizhou province. What is more, it is necessary to reduce the cost of raw material as much as possible to down the price of biochar-based fertilizer, and then promote the use of biochar-based fertilizer in agricultural production and further increase the farmers' economic benefits.

## Conclusion

Results in this study indicated that the supply of biochar-based fertilizer significantly increased the yield and fruit quality, improved the fertilization efficiency and economic benefits of pod pepper in Guizhou province, China. Hence, the application rate of 2550 kg $ha^{-1}$ biochar-based fertilizer containing 30% of corn stalk biochar might be considered the optimum treatment in terms of yield, fruit quality, fertilization efficiency and economic benefits. We should take full use of straw returning to improve the soil quality and use inorganic fertilizers to maintain the soil fertility and crop demands. Although there have been many studies conducted on biochar-based fertilizer to study the plant responses, and the mechanisms that are influenced by biochar-based fertilizer remain poorly understood. More studies will be continued to study the effects of application of biochar-based fertilizer on soil and expect to provide more reliable theoretical basis and data support for the application of biochar-based fertilizer.

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