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*Full Length Article*

# Biochar Contributes to the Release of Potassium in Paddy Soil to Improve Tobacco Growth

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## Abstract

A 3-year pot experiment (2016–2018) was conducted to verify the connection between tobacco potassium (K) accumulation and soil chemical properties along with K bacteria activity for biochar addition. Biochar (BC) was added once into the soil at four rates: 0, 5, 10 and 15% (dry biochar weight/wet soil weight) to evaluate the release and transformation characteristics of K and tobacco growth sown in paddy soil. Compared to K accumulation value (KAV) from the control treatment (CK; with no BC), applied BC improved KAV by 12.1–16.6% in the 10–15% BC treatments in the first year; second-year, KAV was increased by 17.4–49.8% in all BC treatments and by increase was 13.4–53.5% in the last year. Compared with CK, the increasing extent of soil K bacteria number in three years was 2.5–15.0%, 2.6–25.8%, and 0.2–25.8%, respectively after BC application. It also improved tobacco plant height and roots fresh weight. Besides, it increased soil available potassium (AK) by 14.1–25.8%, 15.2–64.8%, and 9.5–61.6% for three consecutive years. In conclusion, addition of BC is seemed beneficial to improve soil K status, tobacco growth and K contents of tobacco leaf. © 2020 Friends Science Publishers

**Keywords:** Flue-cured tobacco; Biochar; Available soil potassium; Potassium bacteria; Potassium accumulation value; Potassium recovery efficiency

## Introduction

Potassium (K), as one of the three major nutrient elements to plants, plays an essential part in plant physiological and biochemical processes (Marschner 2011). Due to K deficiency, some metabolic activities and tolerance of plants are severely affected (Pettigrew 2008; Shabala and Cuin 2008). Tobacco (*Nicotiana tabacum* L.) is an important economic crop with about one million acres each year in China. Potassium is crucial for tobacco leaves, and the growth of tobacco depends mainly on its supply in the soil. It is not only a critical nutrient element but also improves the flammability of flue-cured tobacco and reduces the amount of tar produced in the combustion process (Zhang and Kong 2014). It can also enhance tobacco identity, leaf color, aroma and taste and so on (Liu *et al*. 2019). K content is one of the essential factors affecting tobacco quality. Therefore, K acts as a critical part of enhancing the yield and quality of agricultural production.

Potassium bacteria, also known as silicate bacteria, are a kind of microorganism that can transform the potassium state from unavailable to available. Besides, it can also release silicon, phosphorus, and other elements for efficient absorption by plants. It is an essential bacterium promoting the rhizosphere growth of extracellular plants. According to statistics, there are approximately 2000~40000 potassium bacteria in 1g cultivated soil (Zhang *et al*. 2017).

The K content of high-quality tobacco leaves should not be less than 2%, but in most tobacco areas of China, the K content is only 1~2% (Bao *et al*. 2015). The lower K content of tobacco leaves restricts the further improvement of tobacco quality. To solve these problems, among other methods, the use of some organic products as soil amendments can promote the soil-plant relationship, thus providing better K conditions in the K-deficiency period (Oram *et al*. 2014).

Biochar (BC) is formed by thermal transformation of waste biomass at high temperatures under anaerobic or aerobic conditions, which is called pyrolysis (Brown 2012). It can be served as a soil conditioner to better soil water and fertilizer holding capacity and crop yield (Oram *et al*. 2014; Hussain *et al*. 2017; El-Naggar *et al*. 2019). Corn (*Zea mays* L.) is a major food crop, with an annual straw output of more than 200 million tons in China. Now, incineration is

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the most widely used method for corn straw disposal, during which a large number of $SO_2$, $CO_2$ and other toxic gases are released into the atmosphere, causing the severe air pollution problem (Shi *et al.* 2014; Chi *et al.* 2017). Therefore, via the anaerobic pyrolysis of corn straw to produce BC can attain the purpose of recycling existing resources and energy, and avoid the severe air pollution hazard caused by incineration.

In this study, the pot experiments have been performed to conduct the influence of the single application of BC on K absorption of tobacco with soil microbial and chemical environments. The results of this study will not only provide consultation for future research but also have a particular reference for the manufacture and application of slow-release K fertilizer.

## Materials and Methods

### Materials

Corn straw gathered from Hunan Agricultural University was used to produce the examined BC at 400–500°C, using an electric BC reactor (Liu *et al.* 2016). Its primary physicochemical properties are presented in Table 1.

### Test crop and experimental soils

Soil was collected from the Farm of Hunan Agricultural University Cultivation Base in Changsha, Hunan, China (113°08′N, 28°18′E). The fundamental properties of the soil used in this study are given in Table 1. The tested flue-cured tobacco variety was Yunyan 87, which has the characteristics of high quality, stable yield, wide adaptability, strong stress resistance and easy curing (Li *et al.* 2001).

### Experimental design

A pot experiment was carried using the acidified paddy soils from 2016 to the end of 2018 in a plastic greenhouse of Hunan Agricultural University. Plants were grown in laboratory pot (18 cm upper diameter × 13 cm lower diameter ×14.5 cm deep) filled with 20 kg soil. Pot trial, a single-factor experiment with a completely randomized design, was demonstrated to investigate the effects of the four BC amounts on flue-cured tobacco and soil. Mulcahy's (Mulcahy *et al.* 2013) research confirmed that the volume concentration required for BC to produce significant biological effects is very high (15%). But Case *et al.* (2012) found that adding low-level biochar (5 or 10%) to the surface soil can also improve the property of the soil. Therefore, in this study following treatments as CK (control without BC), C-5, C-10, and C-15, following the numbers denoting the percentage of BC fortified were used. For each season, tobacco seeds were cultivated in the seedling bed on May 1, and transplanted on May 15 with one seedling per pot, and harvested in September. Experiment was laid out following completely randomized design (CRD) and repeated 20 times.

**Table 1:** Physicochemical properties of experimental materials

| Items | Paddy soil | Biochar |
|---|---|---|
| BD (g cm$^{-3}$) | 1.12 | 0.21 |
| SSA (m$^2$ g$^{-1}$) | | 15.4 |
| OM (g kg$^{-1}$) | 32.52 | 326.79 |
| pH | 5.86 | 9.43 |
| TP (g kg$^{-1}$) | 0.49 | $2.51\times10^{-3}$ |
| AP (mg kg$^{-1}$) | 27.67 | 1.09 |
| TK (g kg$^{-1}$) | 5.14 | 0.21 |
| AK (mg kg$^{-1}$) | 121.73 | 38.27 |
| TN (g kg$^{-1}$) | 1.32 | 0.043 |

Abbreviations: BD, bulk density; SSA, specific surface area; OM, organic matter; TP, total phosphorus; AP, available phosphorus; TK, total potassium; AK, available potassium; TN, total nitrogen

CK = treatment without biochar; C-5 = 5% biochar; C-10 = 10% biochar; C-15 = 15% biochar

After tobacco harvesting, removed the remaining roots in the pot. To meet the needs of crop normal growth and development carried out appropriate irrigation during tobacco development according to weather and crop growth conditions. During the growing stage, tobacco has put a unified management strategy. The amount of fertilizer used in each treatment was the same. Recommended NPK fertilizers as N, $P_2O_5$, and $K_2O$ (150, 90, 370 mg kg$^{-1}$) were applied as pure ammonium nitrate, potassium dihydrogen phosphate, and potassium nitrate, respectively.

### Plant sampling and analysis

After 25, 40, 55, 70 and 85 days of transplanting, three tobacco seedlings were randomly selected and sampled. According to the survey method specified in the tobacco industry standard, the tobacco growth parameters were determined in the harvesting time, including plant height, effective leaf number, root length and fresh weight. Then, in the time as mentioned above, plants were bagged according to the parts of the root, stem, and leaf. The dry matter weight (DMW) of the corresponding parts was determined by sterilizing at 105°C for 30 min and baking at 80°C until constant weight. K content in tobacco leaves was determined by the Laboratory Flow Analyser (PULSE3000) of the National Tobacco Cultivation Physiological and Biochemical Base, referring to the standards of the tobacco industry. Calculated K accumulation value (KAV) and at 85 days after transplanting calculated K recovery efficiency (KRE).

At the same time, soil samples were taken, left to dry naturally, and after 2 mm sieve. The underlying properties of the soil were determined according to Baoshidan's (Baoshidan 2000) ‘Soil Agrochemical Analysis’. Total potassium (TK) determination using sodium hydroxide, flame photometry. Avail-K (AK) was referred to as ammonium acetate leaching.

For soil microorganisms, the number of K bacteria in soil samples was measured on 5 sampling days. K-solubilizing bacteria in rhizosphere soil were counted with the silicate medium dilution plate method described by Razzaghi (Komaresofla *et al.* 2019). The result, the number of rhizospheric K bacterial isolate, was reported as colony–forming units (CFU) g$^{-1}$ soil weight.

### Calculation

The following parameters were calculated based on dry matter weight (DMW) and the K concentrations in different organs:

$$\text{KAV(g/plant)} = \text{DMW} \times \text{K concentration}$$

$$\text{KRE(\%)} = \frac{(KU_{BC} - KU_{CK}) \times 100}{QKF}$$

Where $KU_{BC}$ is K uptake in BC added plot; $KU_{CK}$ is K uptake in no BC added plot; QKF is quantity of K applied in each treatment.

### Statistical analysis

Collected data were analyzed using SPSS software (19.0 version of SPSS Company, Chicago, Illinois, U.S.A.) to check the overall significance of data while Tukey test was used to compare the treatments means at $P < 0.05$.

## Results

### Plant growth parameters

Biochar application had significant effect ($P \leq 0.05$) on plant height, root length and fresh weight of tobacco plants and had non-significant effect on number of leaves (Table 2). However, C-15 was found to be more effective to promote plant height as it caused up to 3.36 and 1.65% increase over C-5 and C-10 treatment. For root length, BC increased by 1.57–6.01 cm but did not reach a significant level.

### Rhizosphere soil potassium bacteria

Fig. 1 shows that the BC application significantly increased the soil K-bacteria number, and the amplification rose with the increase of application amount. Compared with CK, the growth rate of soil K bacteria in three consecutive years was 2.5–15.0%, 2.4–25.8% and 0.2–25.8%, respectively. It can be seen that the growth range gradually decreases, and in the third year, there was no significant difference between C-5 and CK. However, C-10 and C-15 were still significantly higher than other treatments.

### Soil potassium supply levels

The addition of BC has significant influence ($P < 0.05$) on available potassium (AK) in soils (Fig. 2). The AK in the BC-adapted soils was 14.1–25.8% greater than CK in the first year, 15.2–64.8% greater in the second year, and 9.5–61.6% greater in the third year.

On the whole, in each period, the AK content of each treatment varied greatly. The treatments with BC were significantly higher than CK, but there was no considerable difference among the treatments of C-5, C-10, and C-15. The comprehensive analysis performed that the BC implementation could improve soil K supply levels, but the content of AK in soil did not rise considerably.

### K recovery efficiency (KRE)

After applying BC, KRE increased more substantially with the amount increasing (Fig. 3). The KRE of different BC amount treatments varied greatly, especially C-15 treatment, which reached 34.70%, low and median BC treatments were 12.11% and 22.80%, respectively. In the second year, compared to 2016, KRE increased by 66.0% in C-15 and 62.5% in C-10, and 50.1% in C-5. In the last year, compared to 2017, KRE decreased by 45.6% in C-5 and 19.8% in C-10, while only 4.4% in C-15.

### K accumulation and distribution dynamics of plants

From Fig. 4, it can be seen that the trend of K accumulation in tobacco plants added BC is the same as the CK, increasing by about 13%. However, after maturity (transplanting days > 70d), K can't still be absorbed and accumulated at a higher rate, even declined, while the dry matter of tobacco plants continues to accumulate. During this period, the K accumulation in tobacco plants decreased by 65%.

In the second year, compared with 2016, the rates of K uptake and accumulation of tobacco plants with BC were speeded up, while the gap with CK was gradually increased from 0.9 to 2.8 g/plant. In the third year, there was almost no significant difference, but it still performs C-15>C-10>C-5>CK.

With the development of tobacco, the K proportion in tobacco leaves increased first and then decreased, especially after maturity, decreased to 65.6%, while the percentage in stems showed a gradual upward tendency (Table 3). Treatments with BC speeded up this trend and favorable to root growth. Over the three years, at 85d after transplanting, the proportion of K in industrial products is relatively high, accounting for 65.6–78.1% of the total potassium uptake, while the proportion of K in non-economic products is relatively low, accounting for only 21.9–34.4%. In non-economic products, stem and root account for a considerable proportion, indicating that the distribution of K in non-BC treatment is more reasonable during the first two years, but it is more consistent in BC treatments in the last year.

## Discussion

BC application improved tobacco growth (Table 2) due to significant improvement in K availability. Potassium is a crucial nutrient for plant growth and development (Manzoor *et al.* 2018). From 90 to 98% of K in the soil exists in various soil minerals and sedimentary materials (Parmar and Sindhu 2013), which cannot be dissolved and absorbed directly by plants. Numerous studies have shown that there are a variety of K-solubilizing bacteria in the soil (Dong *et al.* 2019). These can promote the transformation of insoluble K and other nutrients into soluble nutrients, which can be immediately uptake by crops, and secrete active substances to improve crop growth, which has an essential contribution to plant absorption (Basak and Biswas 2008).

**Table 2:** Effect of biochar application on plant height, number of leaves, root length and root fresh weight of tobacco plants

| Year | Treatments | Plant height (cm) | Number of leaves per plant | Root length (cm) | Root fresh weight (g plant$^{-1}$) |
|---|---|---|---|---|---|
| 2016 | CK | 98.0 ± 0.00b | 15.7 ± 0.47$^{NS}$ | 30.34 ± 0.55b | 270.43 ± 8.56b |
| | C-5 | 98.7 ± 0.47ab | 16.0 ± 0.00 | 32.38 ± 1.94a | 277.29 ± 5.27ab |
| | C-10 | 99.3 ± 0.47a | 16.3 ± 0.47 | 35.85 ± 2.49a | 283.95 ± 4.06ab |
| | C-15 | 97.0 ± 0.00c | 16.3 ± 0.47 | 36.35 ± 3.74a | 287.21 ± 5.04a |
| 2017 | CK | 97.7 ± 0.47d | 15.7 ± 0.47 | 31.02 ± 2.78a | 275.71 ± 10.61b |
| | C-5 | 99.3 ± 0.47c | 16.0 ± 0.82 | 33.83 ± 2.87a | 285.24 ± 3.69b |
| | C-10 | 101.0 ± 0.82b | 15.7 ± 0.47 | 35.08 ± 3.49a | 291.03 ± 4.00ab |
| | C-15 | 102.7 ± 0.47a | 16.3 ± 0.47 | 36.78 ± 2.42a | 302.93 ± 6.00a |
| 2018 | CK | 93.2 ± 0.24c | 15.3 ± 0.94 | 30.87 ± 4.92a | 273.49 ± 3.03b |
| | C-5 | 95.7 ± 0. 62b | 15.3 ± 0.47 | 32.44 ± 3.42a | 282.51 ± 5.89ab |
| | C-10 | 96.5 ± 0.41ab | 16.0 ± 0.00 | 34.43 ± 4.74a | 286.07 ± 7.41a |
| | C-15 | 97.3 ± 0.47a | 16.3 ± 0.47 | 36.32 ± 3.18a | 291.71 ± 3.71a |

Means ± standard deviation sharing same letters differ non-significantly ($P > 0.05$)
CK = treatment without biochar; C-5 = 5% biochar; C-10 = 10% biochar; C-15 = 15% biochar

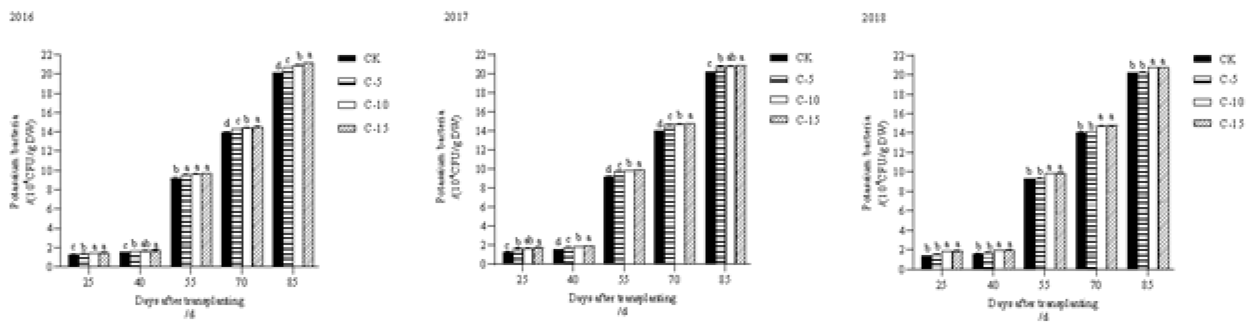


**Fig. 1:** Effect of biochar application on potassium bacteria in rhizosphere soil during different growth periods
CK =treatment without biochar; C5 = treatment with 5% biochar; C10 = treatment with 10% biochar; C15 = treatment with 15% biochar. Each histogram is mean value of 3 replications ± S.E, where vertical bars different letters on bars are showing statistical differences at P ≤ 0.05 represent the standard deviation of means each treatment (n=3)

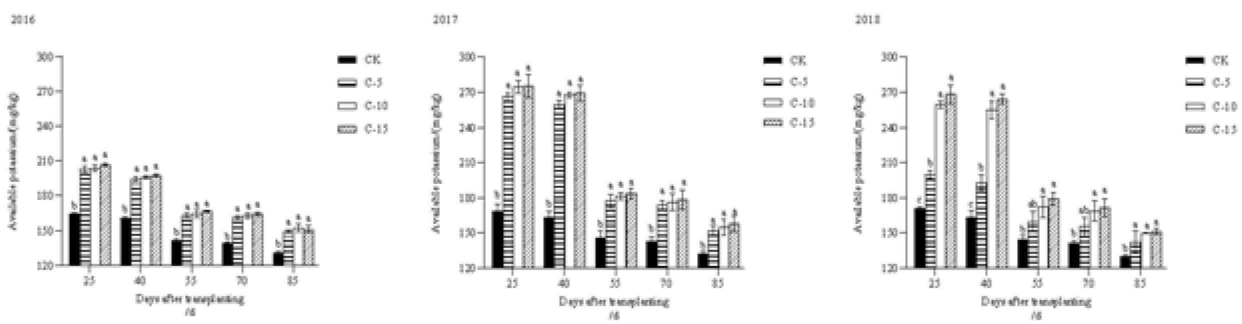


**Fig. 2:** Effect of biochar application on the available potassium during different growth periods
CK =treatment without biochar; C5 = treatment with 5% biochar; C10 = treatment with 10% biochar; C15 = treatment with 15% biochar. Each histogram is mean value of 3 replications ± S.E, where vertical bars different letters on bars are showing statistical differences at P ≤ 0.05 epresent the standard deviation of means each treatment (n=3)

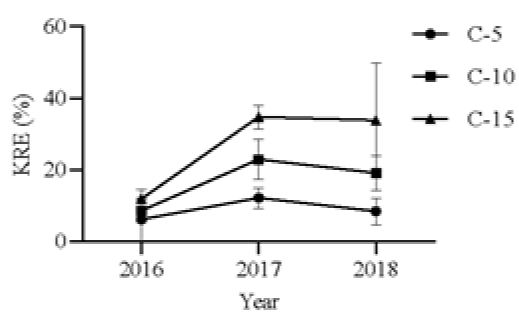


**Fig. 3:** Effect of biochar application on potassium recovery efficiency (KRE)
$KRE(\%) = \frac{(KU_{BC} - KU_{CK}) \times 100}{QKF}$, where $KU_{BC}$ is K uptake in BC added plot; $KU_{CK}$ is K uptake in no BC added plot; QKF is quantity of K applied in each treatment
C5 = treatment with 5% biochar; C10 = treatment with 10% biochar; C15 = treatment with 15% biochar. Each dot is mean value of3 replications ± S.E

**Table 3:** Effect of biochar application on K absorption and distribution in tobacco at different transplanting days in three years

| Year | Days after transplanting (d) | Treatments | Root (g plant$^{-1}$) | Distribution ratio (%) | Stem (g plant$^{-1}$) | Distribution ratio (%) | Leaf (g plant$^{-1}$) | Distribution ratio (%) | Whole $K^+$ (g plant$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| 2016 | 25 | CK | 0.05 ± 0.00a | 5.29 | 0.28 ± 0.03a | 27.74 | 0.67 ± 0.08a | 66.97 | 1.00 ± 0.05a |
| | | C-5 | 0.04 ± 0.00b | 4.76 | 0.25 ± 0.01ab | 28.44 | 0.59 ± 0.07a | 66.80 | 0.88±0.07ab |
| | | C-10 | 0.04 ± 0.00ab | 5.30 | 0.20 ± 0.01b | 24.40 | 0.57 ± 0.18a | 70.29 | 0.81±0.18ab |
| | | C-15 | 0.04 ± 0.00b | 5.11 | 0.20 ± 0.04b | 27.27 | 0.50 ± 0.06a | 67.62 | 0.74 ± 0.07b |
| | 40 | CK | 0.26 ± 0.02b | 8.12 | 0.67 ± 0.29a | 21.13 | 2.26 ± 0.23a | 70.74 | 3.19 ± 0.07a |
| | | C-5 | 0.33 ± 0.01a | 11.07 | 0.75 ± 0.32a | 25.57 | 1.87 ± 0.09b | 63.36 | 2.94 ± 0.42a |
| | | C-10 | 0.33 ± 0.01a | 11.85 | 0.60 ± 0.29a | 21.56 | 1.86 ± 0.05b | 66.59 | 2.79 ± 0.33a |
| | | C-15 | 0.31 ± 0.01a | 10.98 | 0.70 ± 0.33a | 24.72 | 1.81 ± 0.08b | 64.30 | 2.81 ± 0.32a |
| | 55 | CK | 0.54 ± 0.02b | 8.87 | 1.61 ± 0.02a | 26.31 | 3.97 ± 0.08a | 64.82 | 6.12 ± 0.10a |
| | | C-5 | 0.69 ± 0.04a | 10.96 | 1.74 ± 0.07a | 27.43 | 3.90 ± 0.13a | 61.60 | 6.33 ± 0.21a |
| | | C-10 | 0.75 ± 0.05a | 12.02 | 1.61 ± 0.06a | 25.95 | 3.85 ± 0.04a | 62.03 | 6.21 ± 0.03a |
| | | C-15 | 0.78 ± 0.03a | 12.66 | 1.69 ± 0.05a | 27.45 | 3.68 ± 0.47a | 59.89 | 6.15 ± 0.49a |
| | 70 | CK | 0.39 ± 0.03b | 4.12 | 2.34 ± 0.05b | 24.65 | 6.76 ± 0.12b | 71.22 | 9.49 ± 0.08b |
| | | C-5 | 0.39 ± 0.01b | 3.93 | 2.38 ± 0.04b | 24.11 | 7.11 ± 0.29b | 71.96 | 9.87 ± 0.29b |
| | | C-10 | 0.46 ± 0.06ab | 4.18 | 2.58 ± 0.02a | 23.54 | 7.91 ± 0.21a | 72.27 | 10.94±0.27a |
| | | C-15 | 0.54 ± 0.05a | 5.05 | 2.32 ± 0.11b | 21.69 | 7.84 ± 0.06a | 73.26 | 10.71±0.14a |
| | 85 | CK | 0.13 ± 0.01b | 2.30 | 1.51 ± 0.05c | 26.67 | 4.03 ± 0.11a | 71.03 | 5.68 ± 0.14b |
| | | C-5 | 0.14 ± 0.01b | 2.28 | 1.53 ± 0.02c | 24.90 | 4.49 ± 0.38a | 72.82 | 6.16±0.37ab |
| | | C-10 | 0.18 ± 0.02ab | 2.86 | 1.71 ± 0.06b | 26.88 | 4.47 ± 0.28a | 70.26 | 6.36 ± 0.35a |
| | | C-15 | 0.23 ± 0.04a | 3.46 | 1.88 ± 0.04a | 28.38 | 4.51 ± 0.06a | 68.16 | 6.62 ± 0.07a |
| 2017 | 25 | CK | 0.07 ± 0.00a | 8.14 | 0.24 ± 0.02a | 26.88 | 0.59 ± 0.08a | 64.98 | 0.91 ± 0.07a |
| | | C-5 | 0.08 ± 0.02a | 7.96 | 0.28 ± 0.03a | 28.44 | 0.62 ± 0.10a | 63.60 | 0.97 ± 0.10a |
| | | C-10 | 0.07 ± 0.02a | 6.93 | 0.28 ± 0.08a | 28.97 | 0.63 ± 0.25a | 64.09 | 0.98 ± 0.36a |
| | | C-15 | 0.07 ± 0.03a | 6.20 | 0.33 ± 0.09a | 31.79 | 0.65 ± 0.25a | 62.02 | 1.05 ± 0.37a |
| | 40 | CK | 0.35 ± 0.04a | 12.14 | 0.71 ± 0.45a | 24.47 | 1.83 ± 0.13b | 63.40 | 2.88 ± 0.41a |
| | | C-5 | 0.46 ± 0.08a | 13.46 | 0.80 ± 0.52a | 23.51 | 2.14 ± 0.11a | 63.03 | 3.39 ± 0.62a |
| | | C-10 | 0.46 ± 0.02a | 13.60 | 0.79 ± 0.16a | 23.39 | 2.12 ± 0.06a | 63.02 | 3.36 ± 0.19a |
| | | C-15 | 0.44 ± 0.11a | 12.37 | 0.84 ± 0.31a | 23.49 | 2.31 ± 0.10a | 64.13 | 3.59 ± 0.17a |
| | 55 | CK | 0.53 ± 0.06a | 7.59 | 1.85 ± 0.35a | 26.35 | 4.65 ± 0.05d | 66.06 | 7.04 ± 0.35b |
| | | C-5 | 0.66 ± 0.17a | 8.04 | 1.96 ± 0.23a | 23.82 | 5.60 ± 0.03b | 68.14 | 8.22 ± 0.30a |
| | | C-10 | 0.74 ± 0.07a | 9.02 | 2.15 ± 0.21a | 26.19 | 5.31 ± 0.05c | 64.79 | 8.19 ± 0.15a |
| | | C-15 | 0.61 ± 0.02a | 6.98 | 2.09 ± 0.23a | 24.06 | 5.99 ± 0.04a | 68.96 | 8.68 ± 0.23a |
| | 70 | CK | 0.75 ± 0.01b | 6.94 | 2.42 ± 0.12b | 22.52 | 7.59 ± 0.24c | 70.54 | 10.75±0.34c |
| | | C-5 | 0.95 ± 0.05ab | 7.26 | 2.63 ± 0.10b | 20.20 | 9.46 ± 0.12b | 72.55 | 13.03±0.21b |
| | | C-10 | 1.18 ± 0.19a | 7.95 | 3.47 ± 0.26a | 23.37 | 10.20 ± 0.30a | 68.68 | 14.86±0.47a |
| | | C-15 | 0.93 ± 0.04b | 6.39 | 3.70 ± 0.17a | 25.40 | 9.95 ± 0.09a | 68.21 | 14.58±0.08a |
| | 85 | CK | 0.10 ± 0.03c | 1.88 | 1.41 ± 0.10c | 25.28 | 4.06 ± 0.07d | 72.84 | 5.58 ± 0.13d |
| | | C-5 | 0.38 ± 0.03b | 5.80 | 1.67 ± 0.13c | 25.49 | 4.50 ± 0.02c | 68.71 | 6.55 ± 0.11c |
| | | C-10 | 0.32 ± 0.05b | 4.26 | 2.01 ± 0.24b | 27.17 | 5.07 ± 0.07b | 68.57 | 7.40 ± 0.32b |
| | | C-15 | 0.50 ± 0.07a | 5.98 | 2.37 ± 0.03a | 28.41 | 5.48 ± 0.15a | 65.61 | 8.35 ± 0.18a |
| 2018 | 25 | CK | 0.05 ± 0.00a | 6.83 | 0.22 ± 0.03a | 27.68 | 0.51 ± 0.03a | 65.49 | 0.78 ± 0.06a |
| | | C-5 | 0.05 ± 0.02a | 6.89 | 0.22 ± 0.02a | 28.19 | 0.51 ± 0.03a | 64.92 | 0.79 ± 0.01a |
| | | C-10 | 0.06 ± 0.01a | 7.11 | 0.23 ± 0.02a | 28.02 | 0.53 ± 0.05a | 64.87 | 0.81 ± 0.06a |
| | | C-15 | 0.06 ± 0.02a | 6.93 | 0.25 ± 0.04a | 29.11 | 0.55 ± 0.03a | 63.96 | 0.86 ± 0.01a |
| | 40 | CK | 0.24 ± 0.01b | 10.17 | 0.61 ± 0.03b | 26.25 | 1.48 ± 0.01c | 63.58 | 2.33 ± 0.03d |
| | | C-5 | 0.26 ± 0.01b | 10.08 | 0.64 ± 0.02b | 24.66 | 1.68 ± 0.02b | 65.26 | 2.58 ± 0.02c |
| | | C-10 | 0.32 ± 0.02a | 11.89 | 0.65 ± 0.02b | 24.26 | 1.72 ± 0.03b | 63.85 | 2.69 ± 0.05b |
| | | C-15 | 0.34 ± 0.00a | 11.68 | 0.72 ± 0.04a | 24.99 | 1.83 ± 0.04a | 63.33 | 2.89 ± 0.07a |
| | 55 | CK | 0.25 ± 0.01d | 4.99 | 1.46 ± 0.02b | 28.69 | 3.39 ± 0.14b | 66.32 | 5.11 ± 0.13c |
| | | C-5 | 0.33 ± 0.01c | 6.65 | 1.49 ± 0.04b | 29.95 | 3.16 ± 0.19b | 63.40 | 4.99 ± 0.14c |
| | | C-10 | 0.44 ± 0.01b | 7.54 | 1.54 ± 0.04b | 26.40 | 3.85 ± 0.20a | 66.06 | 5.83 ± 0.18b |
| | | C-15 | 0.51 ± 0.03a | 7.93 | 1.70 ± 0.09a | 26.54 | 4.20 ± 0.18a | 65.53 | 6.42 ± 0.25a |
| | 70 | CK | 0.22 ± 0.03c | 3.11 | 1.62 ± 0.06b | 23.46 | 5.07 ± 0.09d | 73.42 | 6.91 ± 0.11d |
| | | C-5 | 0.27 ± 0.03c | 3.53 | 1.58 ± 0.03b | 20.50 | 5.87 ± 0.05c | 75.97 | 7.72 ± 0.10c |
| | | C-10 | 0.50 ± 0.02b | 5.45 | 1.80 ± 0.08a | 19.56 | 6.90 ± 0.08b | 74.99 | 9.20 ± 0.17b |
| | | C-15 | 0.61 ± 0.05a | 6.14 | 1.94 ± 0.10a | 19.71 | 7.30 ± 0.16a | 74.15 | 9.85 ± 0.23a |
| | 85 | CK | 0.08 ± 0.03c | 1.58 | 1.19 ± 0.06c | 23.89 | 3.71 ± 0.08b | 74.53 | 4.97 ± 0.10b |
| | | C-5 | 0.10 ± 0.01bc | 1.73 | 1.14 ± 0.09c | 20.18 | 4.40 ± 0.28ab | 78.09 | 5.64 ± 0.21b |
| | | C-10 | 0.18 ± 0.04b | 2.76 | 1.49 ± 0.05b | 22.94 | 4.83 ± 0.33ab | 74.30 | 6.50±0.30ab |
| | | C-15 | 0.35 ± 0.06a | 4.54 | 1.72 ± 0.05a | 22.57 | 5.56 ± 1.21a | 72.89 | 7.63 ± 1.19a |

Means ± standard deviation sharing same letters differ non-significantly ($P > 0.05$)

CK = treatment without biochar; C-5 = 5% biochar; C-10 = 10% biochar; C-15 = 15% biochar

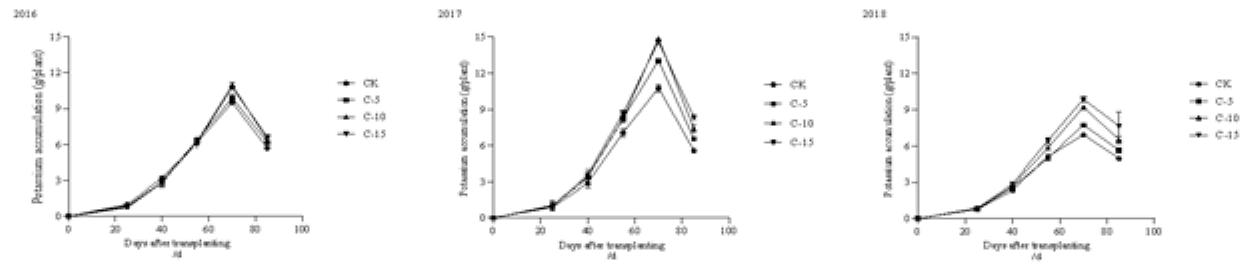


**Fig. 4:** Effect of biochar application on tobacco K accumulation curve
CK =treatment without biochar; C5 = treatment with 5% biochar; C10 = treatment with 10% biochar; C15 = treatment with 15% biochar. Each dot is mean value of 3 replications ± S.E

In this study, after three years of research and one-time BC use, the number of K bacteria in tobacco planting soil significantly increased, which was consistent with the previous research results (Zheng *et al*. 2019). Chen and Du (2015) also found that the application of BC increased the amount of K bacteria in tobacco field soil by 16.1%.

In the present study, AK and KAV were greatly raised over three years in the soil backing the C-15 compared to CK. This phenomenon can be explained by the application of BC to increase the number of soil potassium bacteria and tobacco root growth. The findings also confirm the latest survey by Singh *et al*. (2019), who discovered a remarkable extension in soil AK after BC incorporation thanks to its characterization. The characterization describes the mechanism at the back of soil K adsorption in paddy soils owing to BC's porosity and interplay with clay minerals. BC addition provoked an increment in net mineralization of K in soil, while as well as adsorbing mineralized K and K bacteria onto the pore rooms and the surface area of BC. Therefore, the porous structure of BC can improve the soil porosity and bulk density, enhance the surface area of soil, increase K bacteria quantitative, accelerate the mineralization and the release of slowly available potassium, and enhance K supply capacity (Asai *et al*. 2009). Thus, it is beneficial to the increase of KAV. This discovery is hoped for having a noteworthy impact on K recovery advancement and K concentration enhancement in tobacco. This, in turn, will bode well for future agricultural behavior to lessen the loss of K to erosion from cultivated lands and to provide the beneficial ecosystem benefits.

Furthermore, increased soil aggregate stability in acidic tropical soils (Hartley *et al*. 2016; Zhang *et al*. 2019) as moderated by BC modification plausibly donated dramatically to enhance K concentration. Also, BC adjustment may induce changes in soil quality, thereby modifying soil K forms.

## Conclusion

BC adjustment created a profound transformation in the chemical and microbial ecology of the paddy soil together with the tobacco growth. BC applied in this study showed a good application potential to improve the soil K contents, but the results of this experiment were obtained under the condition of potting. The mechanism of BC and its field application effect need further study.

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