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Effects of Biochar from Spent Mushroom Substrate on Physic-chemical Properties during Pig Manure Composting

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Abstract

Spent mushroom substrate (SMS), a bulky waste byproduct of commercial mushroom industry, causes serious environmental issues and significant barrier to the future expansion of this industry. Biochar from SMS was produced to improve bio-fertilizer quality, the effects of SMS biochar derived from 500 ℃ pyrolysis on physic-chemical properties during pig manure composting were mainly studied in this work. The biochar was mixed with pig manure at additive rate of 0, 5, 10 and 15% (w/w). The results show that the biochar amendments significantly reduced the electrical conductivity, initial moisture content and the loss of organic matter of the compost. From the macronutrients analysis, additive biochar significantly increased the concentration of N, whereas had no significant influence on Ca and K. The concentrations of P and Mg in the fertilizer increased comparing to the control, but the change showed a decline trend with the increase of biochar. Moreover, biochar addition could also effectively promote the growth of rice and enhanced the grain yield by 49% in maximum.

Keywords: Spent Mushroom Substrate; Biochar; Composting; Physicochemical Property; Rice Cropping

1 INTRODUCTION

Spent mushroom substrate (SMS) is a by-product from mushroom production industry, generally represented by agricultural wastes, animal manure, and other materials. Huge amount SMS is produced from mushroom production and has not been treated effectively in China. The potential economic impacts of recycling SMS are significant [1]. SMS has been explored to some potential commercial applications, such as soil bioremediation [2], energy feedstock [3-5], and biofertilizer [6-8]. However, no report on the utilization of biochar from SMS was found.

Recently, some studies have proved the benefit of applying biochar in terms of mitigating global warming and as a soil amendment to improve soil quality and crop productivity [9]. According to laboratory incubation and field observation, biochar is more stable relative to other soil organic matter forms [10]. Moreover, the long-term benefits of biochar application potentially include reducing the loss of nutrients, increasing adsorption ability, soil organic carbon and the size of soil microbial community [11], thus improving soil fertility [12-15]. In contrast to the well-proved positive effects of biochar on soil, there are few researches on the effect of biochar on the quality of compost. Composting is a widely-accepted technology for treating organic waste in agriculture. Composting technology can resolve some environmental problems related to the waste management by decreasing volume, degrading toxic compounds and killing potentially dangerous organisms. It is based on the biological transformation of the organic wastes under aerobic conditions, with the participation of a wide range of microbial groups [16]. According to recent studies [17], biochar as a composting component has shown positive effects, reducing the losses of nitrogen and other nutrients from the compost matrix and enhancing compost quality by increasing the degree of organic matter humification [18]. Jindo et al. [16] examined the addition of hardwood-derived biochar to compost mixtures. The results show that the biochar could induce changes in the microbial community present. But it is still necessary to gain further insight into the effects of biochar on physic-chemical property during composting. Therefore, the purpose of the present work was to investigate the effects of SMS biochar on the changes of chemical and physical properties during the composting.

2 MATERIALS AND METHODS

2.1 Substrates and Biochar Production

Fresh pig manure and rice straw were used as experimental materials and were collected in polyethylene boxes from poultry farms in a suburb of Tong an (118 °E, 24 °N), Fujian province, China. Before composting, the rice straw was dried at 60 °C for 24 h to <10% moisture and cut to pieces around 8 cm long.

The SMS used in the present study was obtained from Ruyiqing Group Co., Xia Men. For pyrolysis, the dry SMS was placed into a quartz container which was housed at the centre of the tubular furnace with a N_2 purge to ensure an oxygen-free atmosphere. The pyrolysis condition was set at the fixed heating rate of about 50 °C /min up to the 500 °C, and then held for 5 h before cooling to room temperature under N_2 flow. The obtained biochar was stored in separate vacuum desiccators.

2.2 Experimental Set-Up and Procedure

The composting was conducted using four identical 100 L reactors made of high-density polyethylene. The reactors were equipped with a valve for dropping the leachate and condensate. Three different biochar amendments were made at application rates of 5, 10 and 15% w/w (referred to as 5% Biochar, 10% Biochar and 15% Biochar, respectively) and homogenously mixed. A control treatment without biochar addition was also included (referred to as control). 2% of rice straw was added into all reactors as a bulking agent. The composting process lasted approximately 42 days.

2.3 Sampling and Analysis

The temperature of the pile was monitored at a depth of 10 cm inside the piles in 4 different points each day during the process with a temperature probe. At the beginning of the composting process (0 days) and after 7, 14, 21, 28 and 42 days, six subsamples were collected randomly from four sites of each pile. The moisture content was analysed by drying the subsample in an oven at 105 °C for 24 h. Electrical conductivity (EC) and pH were carried out in aqueous extract using pH meter model UB-7 (Ultra Basic, US) and a conductivity meter model Cond 3110 (Tetracon 325, Germany), respectively. This aqueous extract was obtained by mechanically shaking the samples with distilled water at 1/5 (w/v) ratio for 30 min. Total C and N were measured by dry combustion using a macro analyzer (VarioMax CNS, Germany). The organic matter (OM) content was measured by loss on burning oven at 600 °C for 4 h. The loss of organic matter (k) was calculated from the initial and final organic matter contents, according to the equation as follows [19]:

$$\mathrm{k} = \frac{[\mathrm{OMb}\ (\%) - \mathrm{OMe}(\%)] \times 100}{\mathrm{OMb}\ (\%) \times [100 - \mathrm{OMe}\ (\%)]}$$

Where OMb is the organic matter content at the beginning of the process; and OMe is the organic matter content at the end of the process.

The concentrations of the elements were determined by using ICP-OES (Perkin-Elmer Optima 7000 DV, Downers Grove, IL), including K, Na, P, Cr, Cu, Ni and Zn. Prior to analysis, the sample (about 0.5 g) was first digested by the concentrated HNO_3/H_2O_2 solutions in a heating reaction system to form the homogeneous solution samples.

2.4 Statistic Analysis

The data were analysed using the statistical package SPSS 19.0. The measures were expressed in terms of mean, while the figures presented the mean values and standard deviation of three replicates. Differences from the treatment methods were tested using analysis of variance (ANOVA), whereas for mean significance the Tukey's test was used with a level of $P< 0.05$.

3 RESULTS AND ANALYSIS

3.1 Properties of Materials

The chemical properties of the pig manure, biochar, and rice straw are presented in Table 1. The pH of pig manure and rice straw were neutral and that of the biochar was alkaline. EC of pig manure and biochar were considerably greater than that of rice straw. Pig manure and SMS biochar had a similar carbon-nitrogen ratio but rice straw had a much greater of carbon-nitrogen ratio. As expected, pig manure, biochar and rice straw had high OM contents.

TABLE 1 SOME CHEMICAL PROPERTIES OF THE MATERIALS USED

Materials	**pH**	**Moisture (%)**	**EC (ms•cm^{-1})**	**C/N**	**OM (%)**
Pig manure	6.73	74.50	3.35	18.72	73.13
SMS biochar	10.90	1.65	3.70	18.69	70.64
Rice straw	7.29	9.09	0.01	43.04	86.71

3.2 Compost Temperatures

Temperature was used as the main parameter to monitor the performance of the compost process. It can be seen from Fig. 1, the composting temperatures in all conditions increased rapidly and then decreased rapidly between days 1 and 3 after treatment. It is evident that temperatures reached around 55 ℃ in all conditions and these maximal temperatures have been maintained very shortly (only few hours). After 28 days, all reactions showed a stable temperature of about 30 ℃.

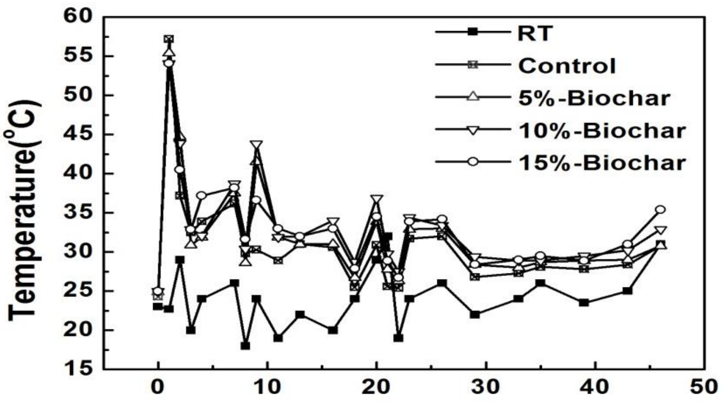

FIG. 1 VARIATION OF TEMPERATURE IN THE COMPOSTS WITH TIME

3.3 Changes of Moisture Content and Electrical Conductivity of Composts

Figure 2 shows changes of moisture contents of compost in all reactors as a function of time. Moisture contents for all reactors decreased continuously during composting and became stable after 28 days. The initial moisture contents of biochar-blended composts (51.45-52.39%) were lower than that of without biochar compost (59.88%).

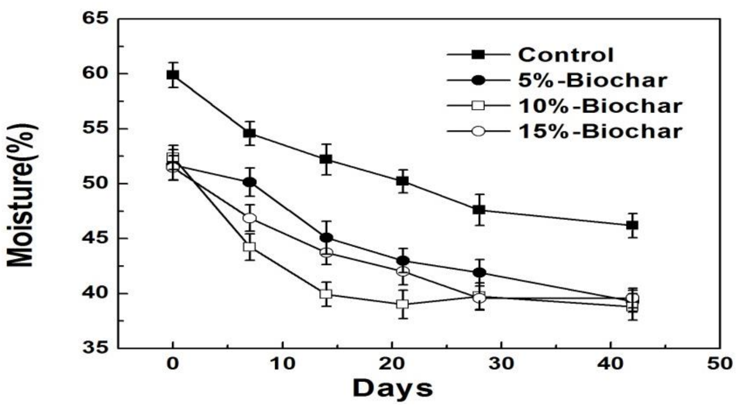

FIG. 2 VARIATION OF MOISTURE CONTENT IN THE COMPOSTS WITH TIME

The evolution of EC in the control and biochar-blended composts is shown in Fig. 3. In all cases, EC values increased during composting. These increase may be due to the loss of weight and release of other mineral salts through the decomposition of organic substances [20]. Increased concentration of soluble salts reflected the progressive mineralisation of the organic matter [21]. At the end of the process, the composting material in control showed the highest EC during composting (7.65 mS/cm). Amendment of composts with biochar resulted in reduced EC values (5.60-5.85 mS/cm).

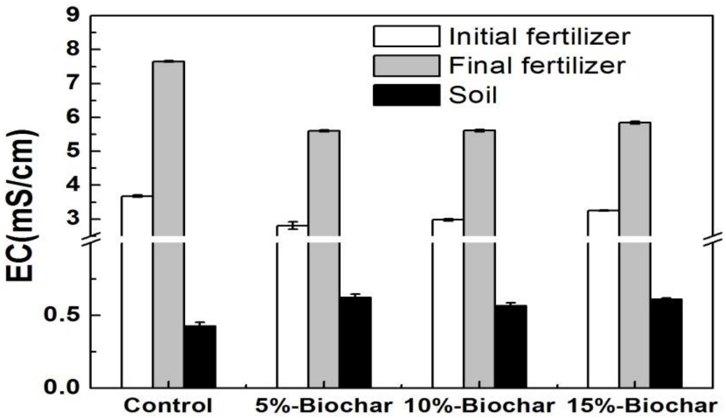

FIG. 3 ELECTRICAL CONDUCTIVITY OF FERTILIZER BEFORE AND AFTER THE COMPOSTS AND SOIL

3.4 Degradation of Organic Matter

During composting process, organic matter is converted to carbon dioxide, ammonia and microbial biomass. In this study, both volume and mass of composting material decreased significantly (data not shown). This decrease was mainly due to the degradation of organic matter by microorganisms during composting process. All reactors were filled with around 17 kg of compost material and about 20 g were sampled from the reactors, which can be neglected compared with the whole composting mass within the reactors. Therefore, the great changes of volume and mass of composting material were caused by to the decrease of moisture and organic matter contents in composting mixture. The loss of organic matter (k) for all reactors was calculated and shown in the Fig. 4. After 42 days of composting, the highest organic matter loss was determined as 31.99% in control treatment, the lowest k value was calculated as 19.32% in the 15% biochar-blended compost. These results corresponded to the low EC values in the biochar-blended compost. The use of biochar reduced the organic matter degradation during the composting process. Biochar has a relative chemical and biological stability due to its high proportion of aromatic structures and high hydrophobicity [22], providing excellent resistance to chemical oxidants and biodegradation [18, 22].

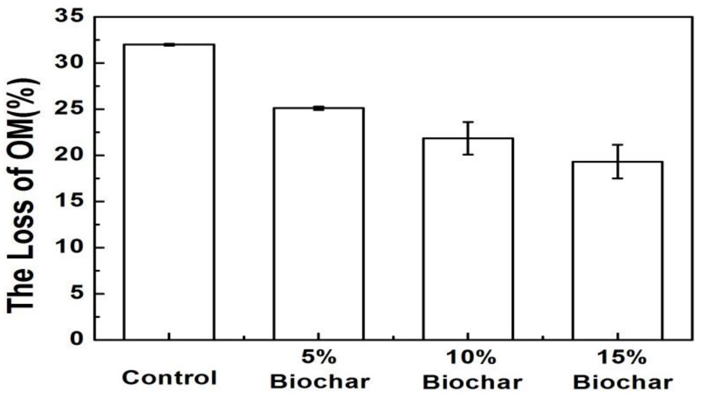

FIG. 4 LOSS OF ORGANIC MATTER AT THE END OF COMPOSTING

3.5 Changes of Elements, Macro- And Micro-Nutrients in the Composting Material

Table 2 shows the concentrations and changes of macronutrients of additive biochar before and after the composting. According to analyse of changes, elements show an increase trend, but most nutrients elements stay the same in the treatment of 15% biochar. K and Mg even show a decrease of 15.5% and 8.93%, respectively. The main reason may be that excessive biochar caused inhibition to bacteria's growth in composting process, thus decreased the decomposition of organic matter, leading to no increase of macronutrients. Comparing the treatment of biochar with control, the concentrations of Ca and K had no significant difference with the addition of biochar, and additive biochar significantly increased the concentration of N, the maximal change was in 15% biochar group. The concentration of P and Mg increased after the addition of biochar, but the changes show a decrease trend with the additive of biochar, the maximal change of P was in 5% biochar group.

TABLE 2 THE CONCENTRATION AND CHANGE OF MACRONUTRIENTS IN THE COMPOSTING MATERIAL

Nutrients	Before composting(mg/g)	After composting(mg/g)	Change (%)
		Control	
Ca	23.90±6.37	41.52±2.09	73.72
N	20.44±0.29	27.84±0.38	36.20
K	42.68±9.34	75.86±1.00	77.74
P	7.61±0.61	10.81±1.21	42.05
Mg	4.38±0.76	7.82±0.23	78.54
		5%-Biochar	
Ca	26.97±5.87	33.33±0.65	23.60
N	21.92±0.59	30.89±1.38	40.92
K	26.61±12.08	54.95±7.12	106.50
P	9.22±1.01	14.33±0.38	55.42
Mg	6.15±1.65	9.26±0.44	9.26
		10%-Biochar	
Ca	22.37±2.04	35.78±0.97	59.95
N	24.25±0.31	34.18±0.05	40.94
K	34.92±3.71	44.65±4.06	27.86
P	12.93±0.94	17.96±0.78	38.90
Mg	7.62±0.99	10.44±0.36	37.00
		15%-Biochar	
Ca	33.37±5.09	33.26±2.08	-0.33
N	24.49±0.51	35.08±0.10	43.24
K	75.64±9.38	63.92±2.88	-15.50
P	18.32±1.91	20.78±0.86	13.43
Mg	13.44±2.07	12.24±0.13	-8.93

3.6 The Effect of Biochar on the Rice Growth

Rice pot experiments under different conditions had been conducted in order to confirm the fertilizer efficiency of biochar based fertilizer. Figure 5 shows the rice height's variation under treatments of without fertilizer, 5% normal fertilizer and 5% biochar fertilizer (refer to Control, 5%-Normal, 5%-Biochar). The addition of 5%-Normal and 5%-Biochar both can promote the growth of rice effectively. The rice height of 5%-Biochar increased about 14% than 5%-Normal while harvesting.

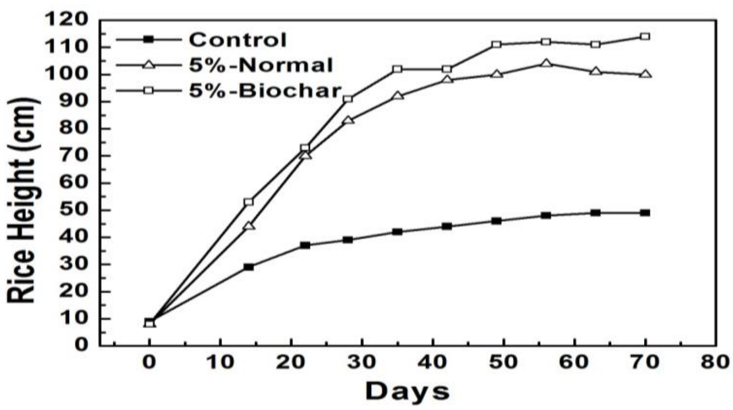

FIG. 5 STRAIN HEIGHT OF RICE UNDER DIFFERENT TREATMENT CONDITIONS

According to table 3, both normal and biochar addition can substantially increase the dry weight of biomass of different parts of rice, and grains weight showed maximal increase. The treatment of biochar had an increase about 19-49% then the normal in biomass dry weight, showing more efficient to the rice growth of rice. The result of additive biochar causing higher biomass height dry weight than the normal treatment coincided with the result of adding biochar in composting causing electrical conductivity decrease and reducing the loss of organic matter mentioned above.

TABLE 3 THE DRY WEIGHT OF GRAINS, LEAVES, STEMS AND ROOTS WHILE HARVESTING

	Control	5%-Normal	5%-Biochar
Grains (g)	0.3a±0.1	14.4b±3.3	21.5c±2.1
Leaves (g)	0.5a±0.2	4.8b±0.6	6.6c±0.6
Stems (g)	0.4a±0.2	6.4b±0.7	7.6b±0.8
Roots (g)	0.3a±0.1	2.0b±0.5	2.8b±0.3

Different letters indicate significant differences between members of the same set ($P \leqslant 0.05$), while similar letters and indicate no significant difference.

4 DISCUSSION

4.1 Compost Temperature

Compost temperature is one of the important parameters of judging the innocuous standard of composting, reflecting the heat accumulation of microorganism metabolic activity and heat-releasing and heat-transferring. It was generally considered the optimal temperature was 55~60℃[18], and all of the treatments of this study reached this range, but the retention time was shorter. The temperature of biochar treatment is higher than the control, indicating biochar had a positive influence on the physic-chemical properties of composting. This result may be due to an increase in biochar surface area or higher water-holding capacity[19], and those conditions were suitable for microorganism metabolic activity [20]. Rapid and vigorous microbial activity resulted in faster composting, shorter residence time and partial pasteurization of the compost causing death of many pathogens [21]。

4.2 Moisture and Electrical Conductivity

Water in the composting system can dissolve the nutrient substance that are good for the activity of microorganism. The evaporation of water brought out the heat, which can have an adjustment on temperature of composting system. The moisture of material in all the treatments decreased continuously and tended to be stable at last. The main mechanism of moisture decrease was that the generation of biological heat and water evaporation made heat transferred in the natural and forced aeration, finally dried the material. The continuous decrease of moisture in composting process indicated the decomposition of organic matter [22]. Biochar has abundant pore structure and high water-holding capacity and can adjust the pH of material. These properties can provide a good environment for microorganism activity, accelerating the metabolism of bacteria. The decrease of moisture in composting was partly due to the absorption and transformation by microorganism activity, as well as due to the evaporation. The addition of biochar in composting had a positive influence, which can adjust the moisture in the initial period and promote the microorganism activity in the process, decreasing the moisture.

Electrical conductivity is an important index reflecting the capability of fertilizer, indicating the physic-chemical properties[23]. High electrical conductivity is harmful to the plant's growth, such as slowing down growth speed, decreasing the yield [24] and burning the seedling. Low electrical conductivity can cause the fast removal of fertilizer in the soil for plant[25]. In general, a substrate with an EC (1:5 soil: water extract) in the range of 0.5~1.5mS/cm was considered moderately saline, 1.5~2.0mS/cm extremely saline and above 2.0mS/cm too saline for most plants [21]. Figure 3 shows that the EC of soil from control was less than 0.5 mS/cm, whereas more than 0.5 mS/cm of the treatment of soil adding biochar and reaching the appropriate scope, suggesting the addition of biochar effectively improving the soil quality by increasing the EC of fertilizer. This result was coincided with the result of the rice yield from different treatments.

4.3 Degradation of Organic Matter

Organic matter was converted into carbon dioxide, ammonia and microbial biomass in the process of composting. Compost material's quantity and volume decreased greatly. This result was due to the decrease of moisture and the decomposition of organic matter by microorganism. The properties of high proportion of aromatic hydrocarbon structure and high hydrophobic made biochar have relative high physical and chemical stability [26], which can prevent chemical oxidation and biodegradation [16, 26], thus reducing the loss of organic matter and improving the quality of fertilizer.

5 CONCLUSION

The effects of SMS biochar added in the pig manure composting on the process and fertilizer's physic-chemical properties were mainly investigates in this work, and rice was taken as experiment plant to test the fertilizer's influence on the yield. Some results were concluded as follows:

1) The addition of biochar in composting had a positive influence, which can adjust the moisture in the initial period and promote the compost maturity by accelerating microorganism activity in the process.

2) The addition of biochar can effectively improve the quality of soil by decreasing the EC of fertilizer and the loss of organic matter.

3) From the macronutrients analysis, additive biochar significantly increased the concentration of N, whereas had no significant influence on Ca and K. The concentrations of P and Mg in the fertilizer increased comparing to the control, but the change showed a decline trend with the increase of biochar.

4) From the pot experiment, biochar addition could also effectively promote the growth of rice about 19-49% then normal in biomass dry weigh and enhanced the grain yield by 49% in maximum.

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