Effects of Mixture Biochar-Fertilizer With and Without Tableting on The Soil Chemical Characteristics

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Abstract. Application of biochar together with fertilizer is a promising strategy to minimize the loss of nutrient through surface runoff and leaching from agricultural field. Biochar has high surface area and can retain nutrients. Despite its advantages, low density of biochar leads to difficult in transporting, handling and mode of application. Our hypothesis is the densification of biochar with fertilizer could reduce transportation and handling costs and minimize loss of nutrient during soil application. Hence, the aim of this study was to determine the effects of mixture biochar-fertilizer with and without tableting on the soil chemical characteristics. There were four fertilization treatments including the control T1 (Soil), T2 (NPK), T3 (Biochar + NPK) and T4 (Biochar tablet embedded with NPK). Mineral clay soils were used and planted with maize. The soil chemical properties were determined for pH, electrical conductivity, total nitrogen, available phosphorus, exchangeable potassium and cation exchange capacity after 53 days planting. The application of biochar tablet embedded fertilizer to soil shows the highest total nitrogen, cation exchange capacity and lower available phosphorus after 53 days planting. The results suggest that the biochar tablet embedded with fertilizer is more efficient to minimize the losses of nutrients in soil.

1. Introduction

Soil fertility plays a vital role in maintaining the health of an agricultural ecosystem. Soil not only supplies the essential nutrients, water and support the crop production but also conserves soil microorganisms and protect water resources. Nevertheless, a rapid human population growth forces conventional farmers to apply high amount of synthetic fertilizers and pesticides to maximize the yield of crops. Application of fertilizer increases the crop yield but accompanied by the emission of greenhouse gases and leaching of nutrient to the ground water if excessively use the fertilizer [1,2].

According to the data from Statistic Department of Malaysia in 2018, Malaysia imported 357,531 tonnes of fertilizers at a cost of RM114.9 million. To reduce the country’s dependence on fertilizer
imports, government puts much effort on promoting the use of organic fertilizer from waste or natural resources. An alternative way to manage the agricultural waste is to convert it into biochar. Biochar is the stable, C-rich charcoal that results from the pyrolysis of agricultural wastes [3]. High mineral ash content and surface area indicate the biochar can be used a suitable soil amendment [3]. In addition, biochar amendment can improve the soil aggregation and thereby significantly reduce the amount of soil loss [4].

Nevertheless, low density of the biochar leads to difficult in transporting, handling and mode of application. It is attributed to large amounts of fine biochar dust are lost in field during the strong wind and heavy rain pour. Otherwise, densification of biochar could reduce transportation and handling costs. It is not sufficient nutrients for the crop yield increment with application of biochar alone in the absent of fertilizer. Literatures report that co-application of biochar with nitrogenous fertilizer had a significant impact on the crop yield [5,6].

High surface area and porosity of biochar make it suitable absorbent to retain the nutrients [7]. This makes nutrients slow release to the soil and thus increase the nutrient uptake efficiency of crops. Nevertheless, there is lack of study on the effects of fertilizer embedded with biochar tablet on the soil chemical properties. We hypothesis that the densification of biochar with fertilizer could reduce transportation and handling costs and minimize loss of nutrient during soil application. Therefore, the objectives of this study were to determine the effect of biochar mixed with fertilizer with and without tabletting on the soil chemical characteristics.

2. Methodology

2.1 Biochar production and preparation
The rubber tree twigs, rice straws and rice husks were the materials used for biochar production. Biochar was produced using a stainless-steel kiln fabricated locally at the Department of Mechanical Engineering Technology, Universiti Malaysia Perlis, Perlis, Malaysia. The average temperature of the kiln throughout the charring process was about 340 °C for 3 hours [8]. The biochar were ground and sieved less than 1 mm prior to their blending with fertilizer and densification process.

2.2 Biochar tablet embedded with fertilizer production
The biochar tablet (BT) was made of biochar rice husk, biochar rice straw, and biochar rubber twigs in a mixture ratio of 5:3:2. Then, the mixture was heated at 100 °C for 5 minutes using a water bath followed by adding NPK Fertilizer (5:3:3). Afterwards, the densification process was done using a single press tablets with a punch weight of 0.4 tonne. Tablets with 6 mm in height and 10 mm in diameter were generated. The BT was oven dried at 60°C for 1 hour and then cooled before keeping in air-tight container.

2.3 Site preparation and soil samples collection
The soil samples were collected from a pot study after the maize planting for 53 days. There were 4 fertilization treatments including the control T1 (Soil), T2 (NPK), T3 (Biochar + NPK) and T4 (Biochar tablet embedded with NPK). The experiment was conducted using a completely randomized design with 5 replications. Mineral clay soils (Malacca series, Oxisol) were used in the experiment. The fertilizers used were ammonium sulphate, triple superphosphate and muriate of potash. The fertilizers were surface applied at 10 and 27 days after planting (DAP). The crops were allowed to grow for 53 days. The soils were sampled from the pots after the crops had been harvested. The soils were air-dried and sieved less than 2 mm for further chemical analysis.

2.4 Soil Chemical Analysis

2.4.1 pH and electrical conductivity (EC)
The pH and EC of soil were analysed using a pH meter and a conductivity meter (Radiometer Analytical, ION check 30) by mixing a 1:5 (v/v) ratio of sample to water after 24 hours with agitation.

2.4.2 Total nitrogen (TN) and available phosphorus (P) analysis
The elemental composition of N was determined using a LECO model TruMac CNS analyzer (LECO Corporation, USA). The soils were extracted with 0.03 M ammonium fluoride and 0.1 M hydrochloric acid for available P analysis according to Bray-2 [9] and the P in the extract was determined colorimetrically [10].

2.4.3 Exchangeable potassium (K), cation exchange capacity (CEC)
Ammonium acetate shaking methods at pH 7 [11] was used to determine exchangeable K and CEC of the soil samples. About 5 g of soil samples was weighed into centrifuge bottle, and added with 1 M ammonium acetate solution. Afterwards, it was shaken for 30 minutes at 180 rpm by using reciprocal shaker. After shaking, the bottle was centrifuged and the supernatant was later filtered using Whatman no.2 filter paper, exchangeable K in the supernatant was determined using automated atomic absorption analyser (AA). To remove free ammonium ion from the soil, the soil was washed with ethanol. It was then shaken for 30 minutes, centrifuged, and the supernatant was discarded. This step was repeated for 2 more times. A 0.1 N potassium sulfate was added in the centrifuge bottle and shaken for 30 minutes, centrifuged, then supernatant was filtered and sent to AA for CEC determination.

2.5 Statistical analysis
The analysis of variance (ANOVA) procedure was used to determine the significant effects of treatments and the treatment means were compared using the Tukey’s test. Statistical Analysis System (SAS) software version 9.2 was used for the statistical analysis.

3. Results and Discussion

3.1 Soil pH and electrical conductivity (EC)
Table 1 shows the pH and EC of soils under different treatments (T1- soil only, T2-NPK, T3-biochar and NPK, T4-Biochar tablet embedded with NPK). The pH and EC are important indicators of the plant availability of nutrients in soil. The soil pH ranges from 5.5-7.0 is desirable for the optimum plant growth [12] while too high EC level (> 4 mS/cm) can hinder the plant growth [13]. The pH of control treatment with soil only had the significantly highest pH (5.63) compare to other treatments. The other treatments with addition of fertilizer, co-application of biochar with fertilizer showed the significantly lower pH than treatment T1. This finding agree with work of [14] who also found that a lower soil pH level with mineral fertilization compared to the control soil. The ammonium ions are oxidized from ammonium sulphate to nitrate and simultaneously release of hydrogen ions during nitrification could acidify the soil.

The highest EC (0.45 mS/cm) was found in the treatment NPK could be attributed to the high mineral salts content in the mineral fertilizer. High EC of soil with NPK treatment (>0.40 mS/cm) can limit the growth of vegetable [15]. Application of biochar-NPK (T3) as well as the biochar tablets embedded with fertilizer (T4) had lower EC were likely due to the presence of calcium, carboxyl and hydroxyl groups in the biochar [8] can reduce the salinity effects of the fertilizer [16].

| Treatments                     | pH   | EC (mS/cm) |
|-------------------------------|------|------------|
| T1- Soil only                 | 5.63a ± 0.01 | 0.02c ± 0.01 |
| T2-NPK                        | 4.76b ± 0.04 | 0.45a ± 0.01 |
| T3-Biochar + NPK              | 4.90b ± 0.11 | 0.36b ± 0.02 |
| T4-Biochar tablet + NPK       | 4.69b ± 0.08 | 0.33b ± 0.01 |
3.2 Total Nitrogen (TN) and Available phosphorus (P)

The highest soil TN (0.19%) was found in biochar tablet embedded with NPK (T4) followed by T3 (0.14%), T2 (0.14%) and T1 (0.11%). The difference between T3 and T4 suggests that densification of NPK with biochar into tablet can bind the element nitrogen and thereby it is not easily leached out from the soil. This results agree with the work of Kim et al. (2014) [17] who also discovered that the densification process binding small particles together and hence reduced the total pore volume of biochar, leading to slow release of nutrients.

Biochar co-application with fertilizer (11.19 mg/kg) and embedded with fertilizer (9.15 mg/kg) showed a lower soil available P than fertilizer. The functional groups of biochar strongly bound with P and slowly released P to soil solution as well as slowed down the P fixation reaction in soils. The data of table 2 suggests that P fixation in soil was the highest in the treatment of NPK application. Similar results have also been discussed by Beji et al. (2017) [18] and Curtin et al. (1993) [19]. High mineral salt concentration in soil increases the soil ionic strength could increase P retention in the soil and make it less mobility to plant uptake.

3.3 exchangeable potassium (K) and cation exchange capacity (CEC)

Data in table 3 shows exchangeable K and CEC of soil under fertilization treatments after 53 days maize planting. The highest exchangeable K was observed in the soils treated with co-application of biochar and fertilizer (0.06%). Incorporation of biochar into soil can increase the soil exchangeable K owing to its high ash K concentration in biochar during the biochar production [20]. However, the biochar tablet embedded with NPK showed lower soil exchangeable K than treatment T3. The difference may be attributed to the lower surface area in biochar tablet embedded with NPK to retain the exchangeable K in the soil compared to the co-application of biochar and NPK without tableting. Although the mixture of biochar and fertilizer had been densified and bound into pellet, high release of K in the pellet has also been discussed by Kim et al. (2014) [17].

Table 2. Total nitrogen (TN) and available phosphorus (P) of soil under fertilization treatments after 53 days maize planting

| Treatments            | TN (%)     | Available P (mg/kg) |
|-----------------------|------------|---------------------|
| T1- Soil only         | 0.11c ± 0.01 | 0.24c ± 0.04       |
| T2-NPK                | 0.14b ± 0.01 | 14.29a ± 0.22      |
| T3-Biochar+NPK        | 0.14b ± 0.01 | 11.19b ± 0.55      |
| T4-Biochar tablet + NPK | 0.19a ± 0.01 | 9.15b ± 0.84       |

Table 3. Exchangeable potassium (K) and cation exchange capacity (CEC) of soil under fertilization treatments after 53 days maize planting

| Treatments        | Exchangeable K (%) | CEC (cmol/kg)    |
|-------------------|--------------------|-----------------|
| T1- Soil only     | 0.004c             | 10.53b ± 0.74   |
| T2-NPK            | 0.04b              | 12.87b ± 0.74   |
| T3-Biochar+NPK    | 0.06a              | 26.53a ± 1.58   |
| T4-Biochar tablet + NPK | 0.04b           | 21.17a ± 1.73   |

Cation exchange capacity is an indicator of soil ability to hold the cation nutrients which are essential for a healthy plant growth. Jiang et al. (2011) [21] found that CEC decreases from 20 cmolc/kg to 7 cmolc/kg with increasing soil age in chronosequences. The soil CEC of control treatment is typical of
soil CEC of Oxisol [22]. Higher soils CEC were observed in T3 (26.53 cmol/kg) and T4 (21.17 cmol/kg) implied that biochar application improved the CEC of intrinsic soil. These findings were consistent with Saha et al. (2019) [23] who also improving the soil CEC through co-application of biochar and synthetic fertilizers. The presence carboxyl and hydroxyl groups in the biochar [8] indicates the chelating potential of biochar to retain more positive-charge ions in soil.

4. Conclusion

Soil nutrient loss is one of the most important causes of agricultural ecosystem degradation. Higher soil total N and CEC was observed in the treatment with application of biochar tablet embedded with fertilizer while higher exchangeable K in the biochar-fertilizer without tableting. Soil application with the biochar-mineral fertilizer can improve the soil chemical quality. Further studies are underway to determine the nutrient uptakes by plants through the co-application of biochar and fertilizer.

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