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Application of biochar coupled with FGD waste for waste management in agriculture improvement

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Abstract. Flue gas desulfurization waste (FGD) is one of coal combustion products (CCP) in coal-fired power plants. Mostly, FGD gypsum is applied in cement and wallboard industry. Also, it can be used in agricultural activities for soil amendment but the amount of FGD waste used in this function is still low. Furthermore, biochar has long been used to improve soil fertility. The positive impacts of biochar amendment on soils are that it can increase soil capacity to adsorb plant nutrients, decrease soil bulk density, increase plant available water retention and so on. In Thailand, some areas like Nan province has a problem of soil degradation from deforestation and excess use of chemical fertilizer. With the benefits of these FGD waste and biochar, the study of soil amendment will be performed by using degraded soil. Therefore, this research is aimed to apply FGD waste coupled with biochar to improve soil quality from degraded soil in Nan Province. Also, the objective of this work is to evaluate the effects of FGD waste and biochar on soil properties such as pH, electrical conductivity (EC), bulk density and soil texture. The concentrations of FGD waste and biochar are ranged from 5-25% and 5-30% by weight, respectively. The results present that the soil quality has been improved in that pH can increase from 5.664 up to 7.309. The soil texture has changed in the better quality from clay to silty loam or loam. Furthermore, the bulk density of soil is reduced in order to have more space for air and water for all mixture which is conducive to plant growth. Consequently, this research can contribute to the improvement of degraded soil properties to fit well for agriculture and the results can be applied for practice in the real field.

1. Introduction

Flue gas desulfurization (FGD) process is the process to remove oxide of sulphur (SO_x) such as the process in coal-fired power plant. According, the report of America Coal Ash Association (ACAA) in 2016, the FGD gypsum is produced about 32 million tonnes, and utilized for 18 million tonnes, that account 57 % of FGD production [1]. FGD material is formed by the reaction between SO_2 and lime slurry or limestone to produce calcium sulphite (CaSO_3). Then the calcium sulphite is further oxidized to calcium sulphate (synthetic gypsum) (CaSO_4) [2]. Mostly, FGD gypsum is applied in wallboard and cement industry, but it can be used in agricultural activities for soil amendment but the amount of FGD waste used in this function is still low. Only 4% of FGD waste is applied [1]. From the properties of FGD gypsum, it can be applied in agriculture to improve chemical and physical limitations of soil, to



prevent soil erosion, to protect water quality, and to enhance the soil capture of rainfall and crop production [3]. FGD gypsum can be used as fertilizer to provide Ca, S and essential nutrients for plant growth [4]. FGD has been used as an amendment to increase soil pH [5]. In 2016, Li et. al., [4] conducted experiment to evaluate affection of FGD gypsum on the chemical characteristic of saline-Na soil in Shanghai tidal flats and plant growth. The results show that, with 25g/kg of FGD gypsum addition, soil salinity can be decreased and enhance plants growth, but at the rate of 50g/kg FGD gypsum is very harmful to plant growth. Furthermore, biochar has long been used to improve soil fertility. Biochar can improve soil quality conditions and crop growth when it is used as a soil amendment alone or in combination with organic and inorganic fertilizers [6-7]. Biochar can reduce the bulk density and increase field capacity of the soil [8]. There is the study has found that biochar can enhance the nutrient and water holding capacities of the substrates, generally more than treatments using peat in place of biochar. In all cases, biochar increased nutrient retention, pH, and pore space, in most cases more than peat [9].

Furthermore, soil degradation is a condition that is severe reduction in the quality of soil. The term includes soil erosion, salinization, soil exhaustion (low fertility), soil acidic or alkalinity etc. The main causes of soil degradation in the world are the overgrazing, overexploitation for fuelwood, agricultural activity, increased flooding and industrialization [10]. In Nan province, Thailand, soil degradation is caused by human activities such as clearing the land and using chemical fertilizer, deforestation, exploitation of marginal soils under inadequate soil management practice [11].

Therefore, this research will apply FGD waste coupled with biochar to improve the quality of degraded soil in Nan Province, and FGD waste and biochar are mixed together for soil amendment. The objective of this work is to evaluate the effects of FGD waste and biochar on soil properties such as pH, electrical conductivity (EC), bulk density and soil texture, and to determine the optimum ratio of FGD waste-biochar-soil combination for improvement of soil degradation. This research is expected that FGD waste and biochar can be applied effectively in agriculture to improve soil quality, decrease the cost of chemical fertilizer, and increase the value of FGD waste.

2. Materials and methods

2.1. Materials

In this research, FGD gypsum is collected from Mae-Moh power plant, Lampang province. Degraded soil and biochar are collected from Nan province, Thailand. Biochar is ground and classified the size from 1 mm to 2.80 mm. The soil properties are measured including soil texture, pH, electrical conductivity (EC) and bulk density.

2.2. Soil texture measurement

The texture of sample is measured in the form of percentage of clay, silt and sand by using hydrometer, and followed the standard of American Society for Testing and Materials (ASTM- D 422 – 63) standard [12]. The experiment results are shown in particle size distribution curve and plotted on soil texture triangle to determine the texture of soil and combinations.

2.3. pH and EC measurement

The pH and EC (1:5) value of the samples are measured by using Benchtop pH/Water Quality Analyzer LAQUA F-74. For the measurement of pH, 10 gram sample with grain size less than 2.0 mm is dissolved with 10 mL distilled water to make the solution ratio at 1:1. For the measurement of EC (1:5), 15 gram sample with the grain size less than 2.0 mm is dissolved with 75 mL distilled water to make the solution 1:5. Each measurement is repeated three times to get the average result.

2.4. Bulk density measurement

Bulk density of samples is measured by using 100 mL graduated cylinder followed the literature [13]. The sample that has passed a sieve No.10 (with the size of 2.0 mm) is added into the cylinder and

compacts the samples by tapping the bottom of the cylinder. Keep tapping and filling the sample until 100 mL of cylinder is filled. Weigh and record weight of the cylinder contain sample. Repeat all procedure for three times to get the average value of bulk density.

2.5. Operating conditions

The concentrations of FGD waste and biochar are ranged from 5-25% and 5-30% by weight, respectively. Table 1 shows the percentage of biochar and FGD gypsum mixed with soil at different ratio.

Table 1. The percentage of biochar and FGD gypsum mixed with soil.

No	Combinations	Ratio
1	Soil + biochar	(95:5)
2	Soil + biochar	(90:10)
3	Soil + biochar	(80:20)
4	Soil + biochar	(70:30)
5	Soil + FGD + biochar	(90:5:5)
6	Soil + FGD + biochar	(80:10:10)
7	Soil + FGD + biochar	(70:20:10)
8	Soil + FGD + biochar	(80:15:5)
9	Soil + FGD + biochar	(70:25:5)

3. Results and discussion

3.1. Effect of biochar and FGD waste on soil texture

Soil texture is an important soil characteristic that influences storm water infiltration rates. The textural class of a soil is determined by the percentage of sand, silt, and clay. The texture of soil is clay, texture of FGD is loam, and biochar is sand. The effect of biochar and FGD waste are presented in Figure 1 and Figure 2, and the results are shown that biochar and FGD waste can reduce clay content in soil and increase silt and sand contents. The texture of soil is changed from clay to clay loam, silty clay loam, loam, silt loam and sandy loam.

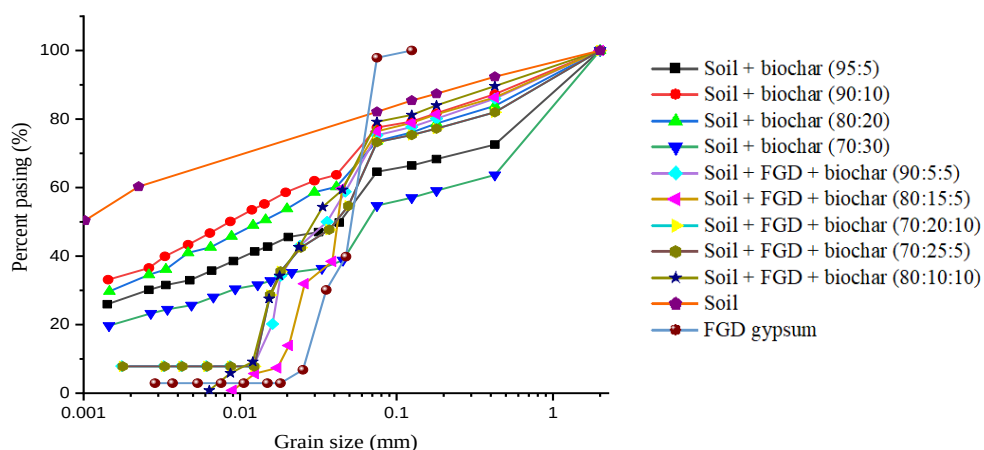


Figure 1. Particle size distribution curve of soil, FGD waste and combination

3.2. Effect of biochar and FGD waste on pH

Soil pH affects the soil physical, chemical, and biological properties and processes, as well as plant growth. The nutrition, growth, and yields of most crops decrease where soil pH is low and increases as pH rises to an optimum level. For example, the optimum pH of corn is 6.8 [14]. The result of pH is

shown that biochar and FGD gypsum can increase pH of soil significantly. First, soil in Nan province is acid with pH at 5.66. Biochar is alkalinity with pH at 10.17 and FGD gypsum is weak alkalinity with pH at 7.87.

The result is shown in the Figure 3 that pH increases when biochar and FGD gypsum are added. The application of biochar at 5% to 20% is considered the best ratio for improvement of soil pH, and it can increase pH of soil from 5.66 to 7.04, but at the ratio 30% biochar, pH of soil becomes weak alkalinity. The application of biochar coupled with FGD gypsum, at the ratio soil + FGD + biochar (80:5:15), soil + FGD + biochar (70:10:20) and soil + FGD + biochar (70:25:5) are the good conditions for soil pH improvement, and pHs of soil increase at 6.31, 6.31 and 6.33, respectively.

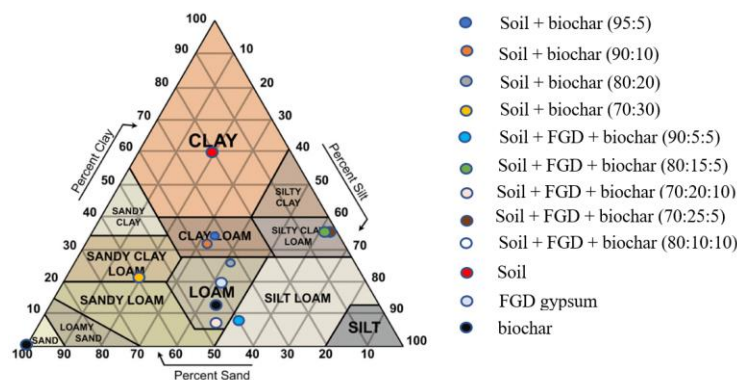


Figure 2. Soil texture triangle with various conditions of mixture.

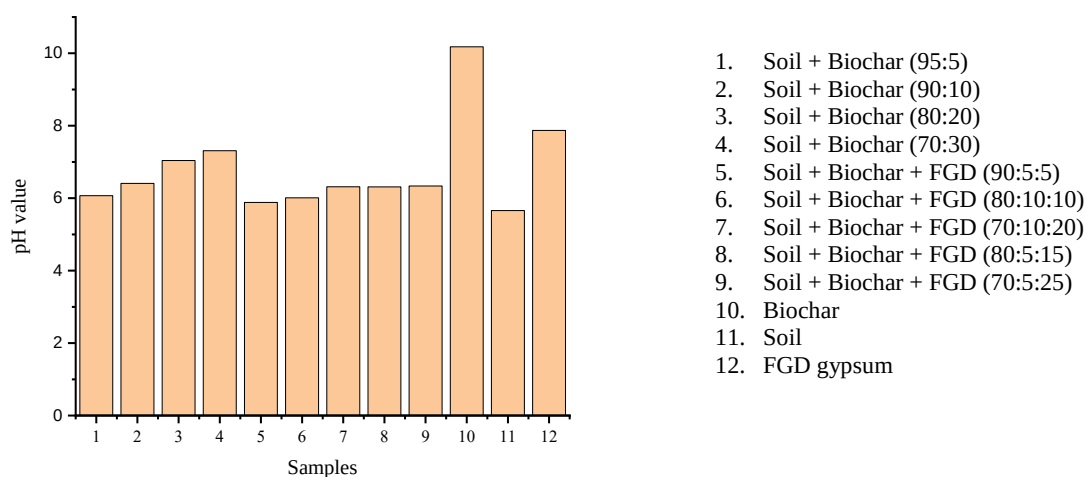


Figure 3. pH result of soil, FGD gypsum, biochar and combinations.

3.3. Effect of bottom ash on Electrical Conductivity (EC)

Soil electrical conductivity (EC) is a measure of the amount of salts in soil (salinity of soil). It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability. In this research, EC_{SE} value of FGD is very high at 37.82 dS/m. Normally, crop yields increase when EC value is low and decrease as EC value rises such as 90% yield of potato is 1.3 dS/m, 75% yield of potato is 1.8 dS/m and 50% yield of potato is 3.6 dS/m [15]. Figure 4 shows that the biochar, FGD gypsum and the mixture can increase EC_{SE} value of soil at all of combination ratios. However, when biochar and FGD gypsum are added into soil, EC_{SE} is still suitable for plant growth.

3.4. Effect of bottom ash on bulk density

Bulk density is an important physical property of soil. It is presented soil compaction and soil health. Bulk density affects with root growth, infiltration, available capacity, plant nutrient availability and soil microorganism activity. High bulk density of soil is an inductor of low soil porosity and soil compaction. It can restrict to root growth, and poor movement of air and water through soil. Each soil will have different ideal bulk density for plant growth and threshold of bulk density value that restricts root growth depending on the texture of soil.

In this research, if soil is clay, normal clay and clay loam, it will be the ideal bulk density for root growth which is lower than 1.10 g/cm^3 and the threshold bulk density is higher than 1.47 g/cm^3 and 1.5 g/cm^3 [15]. The result of experiment of bulk density is shown in Figure 5. Following the experiment biochar and FGD gypsum can reduce bulk density of soil from 1.27 g/cm^3 to 0.76 g/cm^3 .

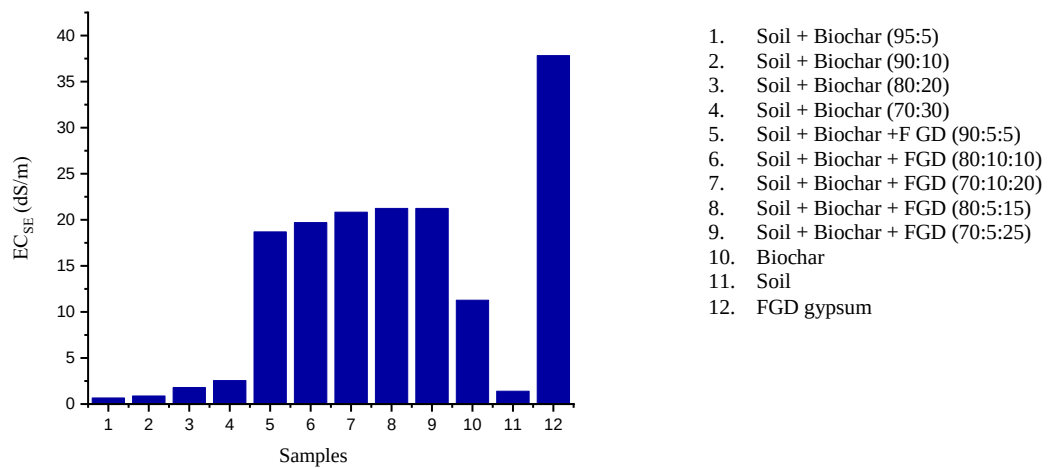


Figure 4. Electrical conductivity of soil, FGD gypsum, biochar and combinations.

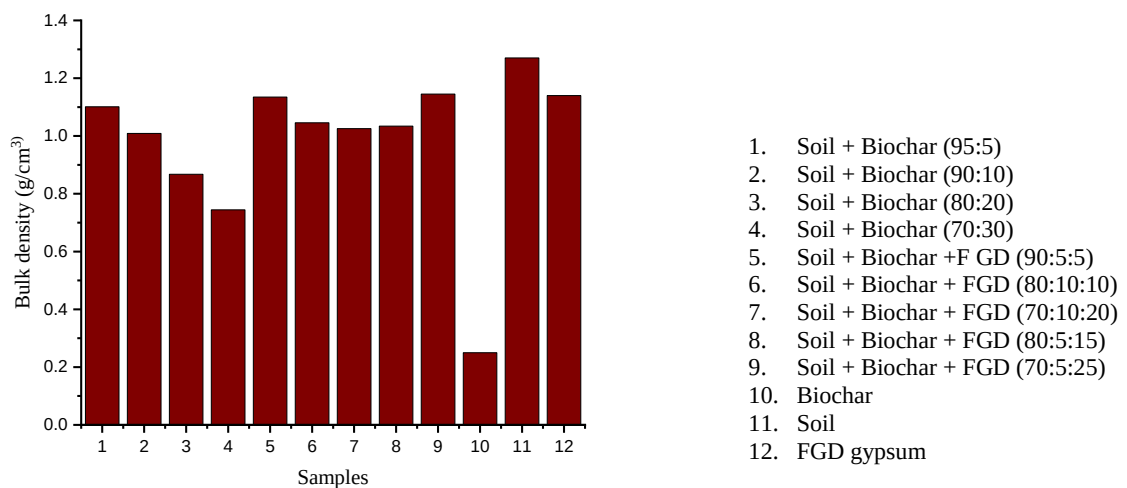


Figure 5. Bulk density experiment result of soil, FDG gypsum, biochar and combinations.

Base on the results of experiment, FGD waste mixed with biochar can be applied for the quality improvement of degraded soil from Nan province in the real field. Therefore, the cost of chemical

fertilizer consumption and waste-management can be decreased. Furthermore, effective land use and friendly environment of waste reduction as well as deforestation can be lower.

4. Conclusion

In this research, the effect of FGD waste, biochar and the mixture are investigated at the of ratio 5-25% and 5-30% by weight, respectively. From the result, the application of biochar and FGD waste can improve soil texture from clay to clay loam, silty clay loam, loam, silt loam and sandy loam. Biochar and FGD waste can increase pH of soil and decrease bulk density of soil at all of ratios. In the case of Electrical Conductivity (EC), FGD waste cannot improve EC of soil, but when use FGD waste coupled biochar, EC value is still suitable for plan growth. Furthermore, the application of biochar coupled with FGD waste at the ratio Soil + Biochar (90:10), Soil + Biochar (80:20), Soil + Biochar + FGD (70:10:20) and Soil + Biochar + FGD (70:5:25) are favourable and considered to apply in the real field to evaluate the improvement on soil properties in the future and are expected that to improve the yield for plant growing.

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