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Application of FGD Waste for Degraded Soil Amendment for Sustainable Agriculture

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The product from coal-fired power plants is flue gas desulfurization (FGD) waste. FGD has been used in many industries such as wallboard and cement industries. It can be applied in agriculture to make soil higher quality. The application of this waste in agriculture is scarce. The benefit of FGD waste can change the acidic condition in soil and increase the substance for plant growing to enhance soil quality. The degradation of soil is one of the main impacts for agricultural industries. Degraded soil is the soil with a decrease in quality because of excessive land use, overuse of chemical fertilizers, deforestation and clearing the land. In Thailand, degraded soil is a crucial problem especially in the northern areas. The aim of this work is to use the FGD waste from coal-fired power plants to enhance the soil quality in Nan, Thailand and to evaluate the effects of FGD waste mixture ranging from 5-40 % by weight on soil texture, bulk density, pH and electrical conductivity (EC). Based on the results, the higher amount of FGD waste in the mixture, the better quality of soil can be obtained, specifically soil texture and pH. The soil texture can be adjusted from clay to silt loam or loam. The pH increases from 5.664 up to 6.861. The soil bulk density reduces for all ratios of mixing with FGD waste which is conducive to plant growth. This study can be used for soil improvement and enhance the agricultural yields. The potential mixing ratios of 30 % to 40 % of FGD waste are expected to investigate the effects on plant growing and soil improvement in the real field for further study.

1. Introduction

The materials for soil amendment can be varied such as bio-waste (Lim et al., 2017), lime and phosphate (Duan, 2018), biochar (Agegnehu et al., 2017) as well as the waste from power plants. From burning coal in power plants and flue gas treating processes, the flue gas desulfurization (FGD) waste is one of the main by-products. It has been used in many applications such as wallboard and cement industries accounting for 69.22 % and 10.47 %. It can be applied in agriculture to make soil higher quality. The application of this waste in agriculture is scarce at 5.05 % (ACAA, 2016). The properties of FGD waste can change pH in soil (Korcak, 1998), provide some plant substances for soil improvement (Wearing et al., 2004) as well as increase soil porosity to have more space for water and air, which improves crop yield (Ramme and Tharaniyil, 2013). The degradation of soil is one of the main impacts for agricultural industries. Degraded soil is the soil with the decrease in soil quality because of the excessive land use, overuse of chemical fertilizers (Aumtong et al., 2009). In Thailand, the soil degradation is a crucial problem especially in the northern part of Thailand like Nan province. In Nan, soil degradation is caused by human activities such as deforestation, clearing the land and excessive use of chemical fertilizer and improper land use (Baicha, 2016).

There are many types of material used to improve soil quality. Duan (2018) investigated the effects of lime and phosphate on lowering soil heavy metal and improving soil quality by taking the conductivity, chlorophyll and content of heavy metal in the plant as the key indicators. Lim et al. (2017) manipulated the recycling organic waste as a soil conditioner to increase plant growth. It provided the soil with nutrients, improved soil texture and water holding capacity and suppressed plant diseases. For this work, FGD waste from coal-fired power plant is applied for soil amendment because more than 20 Mt of coal is burned in power plants each year and

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the huge amount of FGD waste is generated. It is basically used for cement industries. The main application is for landfill. It causes environmental concern and it costs more for water management. The aim of this work is to use the FGD waste from coal-fired power plant to enhance the quality of degraded soil and to assess the effects of FGD waste as a mixture with soil ranging from 5-40 % by weight on bulk density, soil texture, pH and electrical conductivity (EC). This work can be applied to increase soil quality. The practical combinations of soil and FGD waste will be studied to fit well with the main crops in the area. This research will be applied to grow plants in the real field to assess the enhancement on soil properties, to lower environmental impacts, and to increase the application of this waste in the future.

2. Experiment

2.1 Chemicals

FGD waste is obtained from the Mae-Moh coal-fired power plant in Lampang province. The pH of this waste is 7.870. The main compositions of FGD waste are sulphur trioxide (SO_3), calcium oxide (CaO) and magnesium oxide (MgO) for 45.70 %, 35.10 % and 3.79 %. Heavy metals in FGD are also measured. Heavy metals are arsenic (As), mercury (Hg), cadmium (Cd), lead (Pb) and chromium (Cr). The concentrations of each heavy metal are 0.23 mg/Kg for Hg, 0.3 mg/Kg for Pb, 1.72 mg/Kg for As, less than 0.25 mg/Kg for Cd and 20.1 mg/Kg for Cr. However, for this study, heavy metals are not investigated. They will be studied for the future project on the plant growing the real field.

Degraded soil sample is obtained from Nan, Thailand with pH 5.664. FGD waste will be combined with degraded soil at some ratios ranging from 0-40 % by weight of FGD waste. The samples of degraded soil and FGD waste are presented in Figure 1.

(a) (b)

Figure 1: Samples of a) soil and b) FGD waste

2.2 Experimental procedure

The pH and EC are measured with the same equipment by means of analyser from LAQUA. The test sample can be prepared by using 10 g of soil and 10 mL of distilled water for pH testing. For EC experiment, 15 g of soil and mixture dissolves in 15 mL of water. Shake the solution for about 2-3 min, then left for 2 min to settle. Repeat the measurement to get the average results.

The soil texture can be measured by the calculation of the percentage of sand, clay and silt in soil, FGD waste and the mixture from the hydrometer and wet sieve based on ASTM-D422-63 standard (2007). The equipment, chemical and experimental procedure for soil texture measurement can be found from the literature as shown in Phan et al. (2019). The result of soil texture represented by the percentage of sand, clay and silt in soil, FGD waste and the mixture will be obtained by plotting the result in the particle size distribution curve to get the type of soil texture of the sample.

According to Tan (2005), a scale, an oven and a 100 mL graduated cylinder are used as the equipment to measure the bulk density. Also, the other equipment, the chemicals and the experimental procedure for bulk density test can be obtained from the previous study as shown in Sengsingkham et al. (2019). All procedures are repeated for three times to get the average value of the bulk density measurement. The limitation of this work is that acidic soil is obtained from Nan province with specific soil properties and the FGD waste is provided from Mae Moh coal-fired power plant with a certain range of composition of alkaline substance in FGD.

3. Results and discussion

3.1 Soil texture measurement

One of the most crucial soil properties is soil texture. It can reflect other properties such as soil compaction, soil structure and water holding capacity. These properties can influence the growth of plant. The plant types will be suitable with the various kinds of soil texture. Based on Abdulazeez (2017), loam type is regarded as a favourable soil for the development of many types of plants and their roots. The effects of amount of FGD waste on soil texture are studied and shown in Figure 2 and Figure 3.

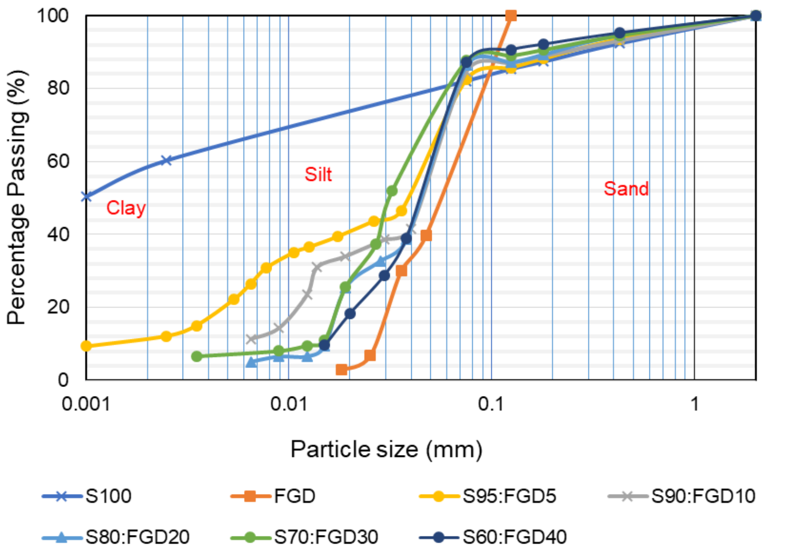

Figure 2: Curve of particle size distribution for soil, FGD waste and the mixture

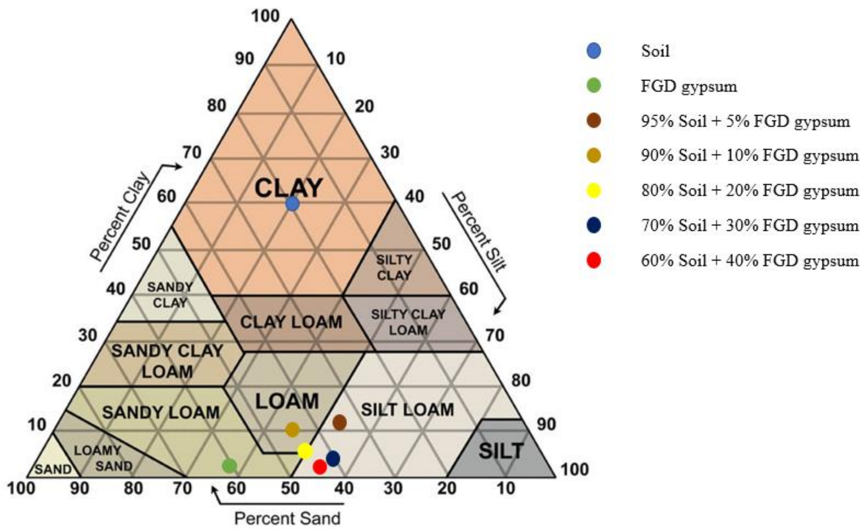

Figure 3: Effect on soil texture for soil, FGD waste and mixture

Figure 2 illustrates the curve of particle size distribution to specify the percentage of sand, silt and clay in the samples, FGD waste and the mixtures. The percentage of clay, sand and silt are plotted in the graph of soil texture to classify the types of soil texture as shown in Figure 3. Degraded soil in Nan is specified as clay, which contains 60 % of clay, 20 % of sand and 20 % of silt as presented in Figure 3. FGD waste from coal-fired power plant is sandy loam, which provides 5 % of clay, 55 % of sand and 40 % of silt. The mixtures of soil and FGD waste are in between both of them. The results present that FGD waste can lower the content of clay in soil and provide more for sand content. With the higher percentage of FGD waste in the mixture, the

soil texture tends to change from clay to loam and silt loam. FGD waste is helpful for soil texture improvement to fit well with plant growth.
The effect of soil texture will be investigated more for the future work on the application of mixture of soil with FGD waste in the real field for plant growing.

3.2 pH measurement

The availability of up-taking the plant growth and the plant nutrients are reflected from pH of soil. According to Smith and Doran (1996), many kinds of plants can grow better in soil with a slightly acid condition. Soil in Nan is acidic with pH at 5.664 and FGD waste from coal-fired power plant is basic with pH at 7.870. From the results, FGD waste can increase soil pH to the level that fit well with plant growing as presented in Figure 4. The combination of bottom ash from 5 % to 40 % is regarded as the suitable combination for the pH adjustment of soil, which improves the soil pH from 5.664 to 6.861.
The effect of pH variation will be studied further for the future work on plant growing in the real field for 2 to 3 times. The change of pH can be occurred because of the weathering and watering.

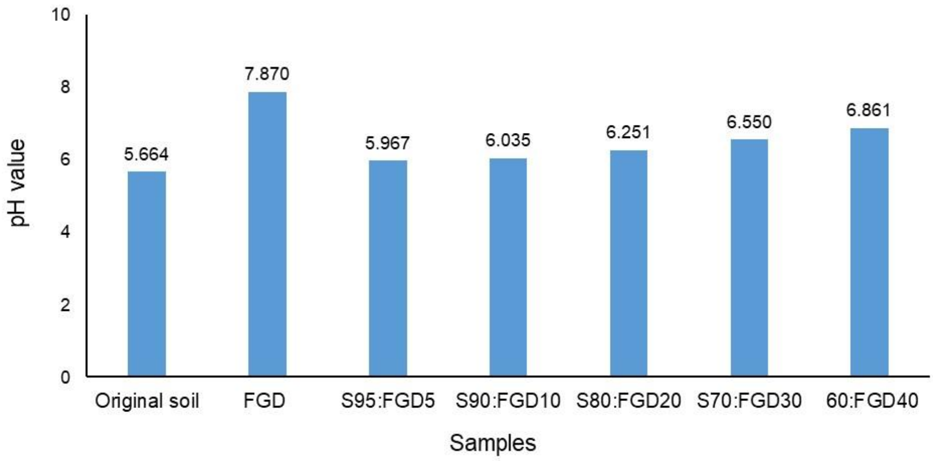

Figure 4: Effect on pH for soil, FGD waste and mixture

3.3 Electrical conductivity measurement

The electrical conductivity (EC) is the main soil characteristic. It represents the concentration of salt in soil which is called salinity. It has the important effect on nutrient availability, microorganisms and crop yields. According to Maas and Hoffman (1977) on the category of crop tolerance to salinity, many kinds of plants cannot grow with EC higher than 32 dS/m. From Figure 5, EC values of soil at many combinations are increased as the percentage of FGD waste in the mixture increases.

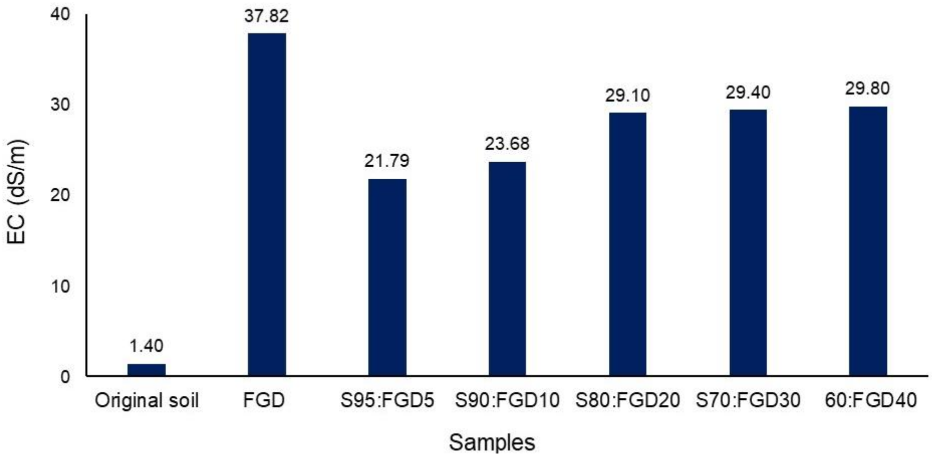

Figure 5: Effect on EC for soil, FGD waste and mixture

Even though the EC value of FGD waste is at 37.82 dS/m, EC value of the mixture ranging from 21.79 to 29.80 dS/m is still fitted for plant growth when FGD waste is combined with soil for all ratios.
The effect of EC can be changed if the mixture of soil and FGD is applied in the real field for plant growing for 2-3 times consecutively as a future work.

3.4 Bulk density measurement

Owing to the effect on the root growth and higher porosity for air and water in soil, another major physical property of soil is bulk density. Bulk density is applied to measure the soil compaction. The root growth, nutrient and water uptake are limited with the soil at high bulk density. Each plant requires a specific range of bulk density for plant growth. Based on USDA (nrcs.usda.gov), the ideal bulk density for the growth of root should be less than 1.10 g/cm^3. From Figure 6, the bulk densities are 1.14 g/cm^3 for FGD waste and 1.270 g/cm^3 for soil. From this study, the mixture of FGD waste can lower bulk density of soil from 1.270 g/cm^3 to 1.180 g/cm^3. Bulk densities of all combinations are greater than the ideal bulk density for plant growth. It is still considered to be suitable with root growth. The effect of bulk density will be presented clearly when applied in the practical work for plant growing.
From the results, the properties of soil after applied FGD waste can be used for the varieties of crops. In this study, it is intended to use FGD waste to improve the soil quality in Nan province, Thailand for plant growing and to provide the optimum combination of FGD waste and soil mixture fitting with plant growth. Growing corn in the real field with the application of FGD waste will be the next research in the future.
The effect of bulk density will be more evident when the mixture is applied for plant growing especially the size, number and root system.

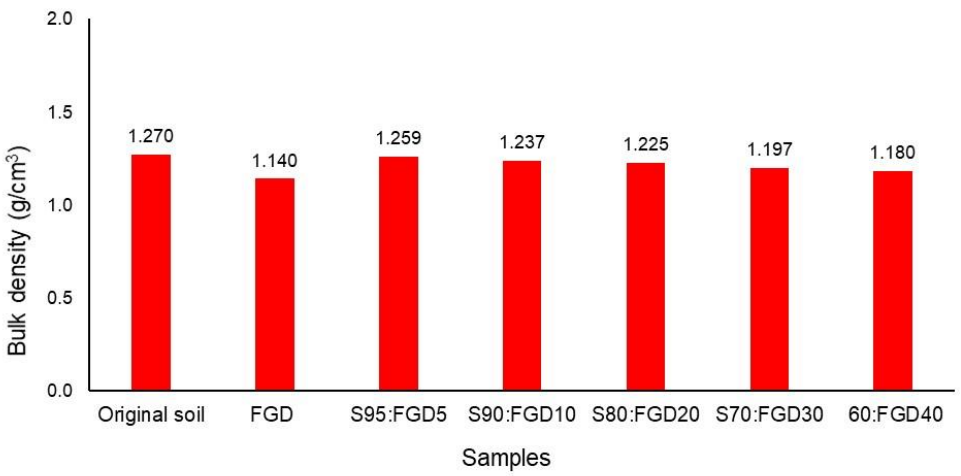

Figure 6: Effect on bulk density on soil, FGD waste and mixture

4. Conclusions

The effects of FGD waste on soil properties are evaluated in various mixing ratios from 0 % to 40 % by weight. The results are clearly presented that the utilization of FGD waste can enhance the soil texture from clay to loam and silt loam at the ratios from 5 % to 40 % by weight. It can adjust the acidic condition or pH of soil to be suitable in the range for plant-growing and lower the soil bulk density at all mixtures to provide more porosity for air in soil. For electrical conductivity, FGD waste has less effect on electrical conductivity of soil improvement, but EC values of the mixture are favourable for plant growth at all combinations. The use of FGD waste can enhance the qualities of degraded soil that fits well with many kinds of plants. The combinations of the FGD waste at 30 % and 40 % by weight are considered as the optimum ratios. For the future work, this research will be applied to grow plants in the real field and to assess the improvement on soil properties with FGD waste at various mixing ratios. In the future, the impacts of this waste on economic, social and environmental applications are that the huge amount of FGD waste can be used in agriculture to improve soil quality and to reduce the cost for growing plants, lower environmental problems both soil and FGD waste, and increase the value of FGD waste instead of dumping it for landfill.

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