Application of soil amendments as a strategy for water holding capacity in sandy soils

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Abstract. Global warming will affect the pattern of precipitation, evaporation, water run-off, soil moisture, and climate variations so that it can threaten food production. High evaporation and unpredictable precipitation will cause drought. Sandy soils have low water holding capacity, high infiltration, and high runoff. The application of soil amendments able to improve the soil’s physical properties through increasing the water holding capacity to increase crop productivity. The research aimed to determine the effect of the application of soil amendments to water holding capacity in sandy soils. The method used was a randomized complete design with one single factor, the type of soil amendments consisting of 7 treatments: P0 (control/without amendment), P1 (cow dung 60 tons ha⁻¹), P2 (rice husk biochar 10 tons ha⁻¹), P3 (clay-soils 10 tons ha⁻¹), P4 (cow dung 60 tons ha⁻¹ + rice husk biochar 10 tons ha⁻¹), P5 (cow dung 60 tons ha⁻¹ + clay-soils 10 tons ha⁻¹), P6 (rice husk biochar 10 tons ha⁻¹ + clay-soils 10 tons ha⁻¹). The results showed that the interaction of rice husk biochar 10 tons ha⁻¹ + clay-soils 10 tons ha⁻¹ significant to increase soil moisture and decrease soil permeability. Combination of cow dung 60 tons ha⁻¹ and rice husk biochar 10 tons ha⁻¹ more increase soil aggregate stability index up to 1.87 times than control.

1. Introduction
Climate change is referred to as a global warming phenomenon, where there is a rise in greenhouse gases in the atmosphere. Climate change and global warming are caused by various factors including the effect of greenhouse gases, damage to the ozone layer, damage to forest functions, uncontrolled use of chlorine carbon (CFC), and industrial exhaust gases. Carbon dioxide, methane, and nitrous oxide are gases that absorb and emit radiation energy, causing a greenhouse effect. Effects of global warming on crops are increasing temperatures, crop damage from extreme heat, increasing moisture stress, and increasing drought. Global warming also will affect the various pattern of precipitation, evaporation, water run-off, and soil moisture. High evaporation and unpredictable precipitation will cause drought.

Indonesia has a very large area of sandy soil with great potential for use as an alternative land for agriculture. However, sandy soil has limiting factors in the water holding capacity, high infiltration, high evapotranspiration, very high soil surface temperature (26–40 °C), very low organic matter, and soil moisture [1], making it less productive for plant growth [2]. The key to improving sandy soil is the addition of soil amendments that the function is to improve soil aggregate, increase water holding capacity, and increase water and air circulation. The material of amendments can be found in the form of cow dung, biochar, and clay-soil. Adding biochar in agricultural soils has been shown as a strategic
solution for mitigating greenhouse gas emissions and also benefits to improve soil characteristics such as water retention, particularly in sandy soils.

Abdala et al. [3] reported that the application of poultry manure on the surface of sandy soil is effectively stabilized the sand particles and increased soil water retention, which was impacted to improved soil structure by the increasing of SOC [4]. Lehman [5], biochar application can increase water holding capacity, CEC, as well as provide nutrients in improving nutrient uptake by plants. The addition of biochar decrease the soil’s bulk density, increases total pore volume, as well as, increases water content at the permanent wilting point [6], and increases soil water repellency [7]. Application of biochar amendment increased water retention capacity, micropore volume, and improved sandy soil structure [8]. Rahayu et al. [9] reported that adding biochar 5 tons Ha\(^{-1}\) is the best result for plant height and number of the tuber of shallot in sandy soil. Addition of biochar 0.5; 2.5; 5.0; and 10 tons tons Ha\(^{-1}\) tend to increase soil C-organic (%) in Ultisols [10].

Clay-soil is reported to be able to affect the organic C sequestration and the water and nutrients holding capacity in sandy soils. However, the effect of clay-soil depends on the properties of clay such as cation exchange capacity (CEC), percentage of clay soil and OC content. Riaz [11] reported that adding clay soil to sandy soil resulted in the largest OC sequestration if the added clay had high clay and CEC content but low OC content. In sandy soils, clay-soil amendments showed higher organic carbon sequestration in all treatments compared to those that were not amended [12] and the addition of subsoil clay to sandy soils has the potential to increase carbon sequestration by increasing the soil organic carbon concentration through adsorption [13]. Therefore, the application of soil amendments in sandy soil is expected to be able to increase the water holding capacity so that the water supplied to the soil will be available for longer, that plant growth is more optimal. Water loss through evaporation and percolation processes will be reduced. The aim of this research was to determine the effect of the application of soil amendments (cow dung, rice husk biochar, clay-soil) to increase water holding capacity in sandy soils.

2. Materials and methods
The research was a pot experiment that carried out in Sukasari, Jumantono, Karanganyar, Indonesia, using a randomized complete design with one single factor, the type of soil amendments consisting of 7 treatments: P0 (control/without amendment), P1 (cow dung 60 tons ha\(^{-1}\)), P2 (rice husk biochar 10 tons ha\(^{-1}\)), P3 (clay-soils 10 tons ha\(^{-1}\)), P4 (cow dung 60 tons ha\(^{-1}\) + rice husk biochar 10 tons ha\(^{-1}\)), P5 (cow dung 60 tons ha\(^{-1}\) + clay-soils 10 tons ha\(^{-1}\)), P6 (rice husk biochar 10 tons ha\(^{-1}\) + clay-soils 10 tons ha\(^{-1}\)). All treatments are replied three times. The material sandy soil that was used from the south coast in Bantul Regency, Yogyakarta. The results of the initial analysis showed in Table 1. The soil was sieved to be homogeneous by separating plant roots and gravel, and then the soil was weighed at 10 kilograms and put into a polybag. Mixed the soil with the soil amendments according to the treatment and incubated for about four weeks. During the incubation period, watering was done every two days and at the end of period incubation (one month), the seedling of chili (Capsicum annum L.) was planted. To ensure the quality of soil amendments, all of the soil amendments were analyzed include soil moisture, pH, organic C, C/N ratio, and soil texture for clay-soil (Table 2). At a depth of 0-20 cm at the end of the research, soil samples were taken and analyzed soil properties such as soil aggregate stability with wet sieving method [14], soil permeability with constant head permeameter method [14], soil moisture, and soil porosity [14]. Data were analyzed using SPSS 23.0, by one-way ANOVA test (F) 5% to compare between treatments, to determine the significant difference between means at a significance level of p <0.05 used DMRT test and Pearson correlation test to determine the relationship between variables.

3. Results and discussion
3.1. Initial analysis of soil characteristics and soil amendments
The results of the initial soil analysis obtained a soil moisture content value of 0.45%, indicating that sandy soil has a low water-holding capacity, water is prone to infiltration and percolation because of its
sand texture with a sand fraction (92.23%), silt fraction (6.81%) and clay fraction (0.96%). The results of the analysis also show that sandy soils have very low organic C (0.18%), very low total nitrogen (0.015%), C / N ratio 14.34, low of available phosphor (7.34 mg kg⁻¹) and available potassium (0.27 cmol kg⁻¹) and very low CEC (4.43 cmol kg⁻¹).

According to Budiyanto [15], coastal sand land is a land that has a soil texture with a sand fraction > 70%, total soil porosity <40%, low water, and nutrient retention capacity because the soil fraction is dominated by macro pores, low soil colloid content so that aeration is fine, aggregate stability index is low, as a result, when it rains, water and nutrients will be easily lost through the process of moving the water down.

Table 1. Initial analysis of sandy soil.

| Parameters | Method | Value | Assessment* |
|------------|--------|-------|-------------|
| pH H₂O (1 : 2.5) | - | 7.12 | Neutral |
| Soil moisture (%) | Gravimetric | 0.45 | - |
| Organic carbon (%) | Walkey and Black | 0.18 | Very low |
| Total nitrogen (%) | Kjeldahl | 0.015 | Very low |
| C/N Ratio | - | 14.34 | - |
| Available P (mg kg⁻¹) | Olsen | 7.34 | Low |
| Available K (cmol kg⁻¹) | NH₄OAc 1 N saturation | 0.27 | Low |
| CEC (cmol kg⁻¹) | NH₄OAc 1 N saturation | 4.43 | Very low |

Texture:
- Sand (%): 92.23
- Silt (%): 6.81
- Clay (%): 0.96

Note. *: Based on the assessment of Balai Penelitian Tanah 2009. Data source: Soil Analysis.

Table 2. Characteristics of soil amendments.

| Soil Amendment | Parameters | Value | Unit |
|----------------|------------|-------|------|
| Cow dung | Soil moisture | 26.96 | % |
| | pH H₂O (1:2.5) | 7.88 | - |
| | Organic carbon | 16.62 | % |
| | Total nitrogen | 0.634 | % |
| | C/N Ratio | 26.39 | - |
| Rice husk biochar | Soil moisture | 8.11 | % |
| | pH H₂O (1:2.5) | 6.14 | - |
| | Organic carbon | 18.07 | % |
| | Total nitrogen | 0.541 | % |
| | C/N Ratio | 33.3 | - |
| Clay-soil | Soil moisture | 0.58 | % |
| | pH H₂O (1:2.5) | 7.10 | - |
| | Organic carbon | 2.13 | % |
| | Total nitrogen | 0.202 | % |
| | C/N Ratio | 10.7 | - |
| | Texture: Silty clay | | |
| | Sand | 8 | (%) |
| | Silt | 43 | (%) |
| | Clay | 49 | (%) |
Utilization of soil organic amendments on sandy soil can improve moisture content, diversity of soil microorganisms, and soil fertility [16]. Naimnule [17], rice husk biochar can improve the chemical, physical, and biological characteristics of soil, increase carbon sequestration in the soil [18][19], reduce nutrient leaching [20], increase CEC [19][21], and increase water holding capacity [22], especially when applied to sandy soils [19]. Various studies have shown that giving rice husk biochar has a positive effect on soil properties and plant productivity.

3.2. The effects of soil amendments on soil moisture, aggregate stability index, porosity and permeability of sandy soil after harvesting

Moisture level measurements were carried out using a Soil Humidity Meter, every day for seven days after harvest. The purpose of measuring moisture content is to determine the best treatment for maintaining soil moisture. The combination of rice husk biochar and clay-soil (P6) was able to increase the best water storage capacity compared to other treatments (Figure 1).

![Figure 1. The effect of soil amendments on soil moisture a week after harvesting.](image1)

![Figure 2. The effect of soil amendments on soil porosity after harvesting.](image2)
The combination of rice husk biochar with clay soil (P6) decreased the permeability value 2.74 times than control (P0) (Figure 3). Giving clay soil to sandy soil requires a long time for incubation so that an increase in aggregation reaction occurs which can reduce the rate of soil permeability which is classified as very fast. The combination of cow dung and rice husk biochar was able to increase soil aggregate stability, 1.87 times compared to control. The addition of straw equivalent to 3.1 tons ha$^{-1}$ and 12.4 tons ha$^{-1}$ was able to increase the soil aggregation up to 100% and 250%, respectively, compared to the control [23] (Figure 4).

This statement is evidenced by the Pearson correlation test value, soil moisture has a strong correlation with aggregate stability ($r = 0.272 \ast$, $P = 0.031$), with increasing soil aggregate increasing soil moisture (Figure 5). Soil aggregation is caused by the addition of clay soil which functions as a binder between particles, making it easier to form sand soil aggregation. This increase was due to the plasticity of the clay soils which increased the cohesion between soil particles. Clay-soils with high plasticity are able to bind between soil particles to form sandy soil aggregates.
Figure 5. Correlation between soil aggregate stability index and soil moisture a week after harvesting

Figure 6. Correlation between soil porosity and soil moisture average a week after harvesting

Figure 6 showed the strong correlation between soil moisture (Figure 1) and soil porosity (Figure 2) \((r = 0.310 \ast, P = 0.0012)\). Rice husk biochar and clay-soil are able to reduce infiltration and thus retain water from leaching [24]. Rice husk biochar can reduce infiltration rate and soil permeability [25]. The small size of the rice husk biochar particles fills the pores between the sand grains and partially closes the soil drainage, thereby affecting groundwater retention by reducing inter-particle macropores (interpora) and increasing micro-pores [26]. When the addition of high biochar, biochar particles can form new drainage channels.
Adding a certain dose of biochar is useful for slowing the infiltration rate to the vertical direction, but excessive addition increases vertical infiltration [25]. The increase in soil porosity affects the decrease in the value of soil permeability as evidenced by the negative correlation between soil porosity and soil permeability ($r = 0.257 \ast, P = 0.041$). High soil porosity can hold water more so that it can reduce the permeability rate (Figure 7). Sandy soils with low organic carbon content have a high level of sensitivity to water retention if there is a change in organic matter content. Increased organic matter content leads to increased water retention in sandy soils [27]. Biochar plays an important role because biochar is chemically able to stabilize nutrients and physically increase the capacity of the soil to hold water and nutrients in soil solution [28]. Global warming has an impact on increasing soil temperature, evaporation, and transpiration which affects water soil availability. The addition of soil amendment in sandy soil in the form of rice husk biochar can increase soil moisture content so that water availability for plants is fulfilled. This shows that the soil amendment can reduce water loss due to evaporation.

4. Conclusion
Global warming increases precipitation, evaporation, water run-off, and decrease soil moisture, and unpredictable precipitation will cause drought. This is not beneficial for agricultural land, especially on coastal sand, which has the characteristics of low water retention, high infiltration, high evapotranspiration, very high soil surface temperature (26-40 °C), very low organic matter, and soil moisture. Application of clay-soils 10 tons ha$^{-1}$ (P2) gave the highest soil moisture value after incubation of 17.59%, an effective increase of 122.69% compared to control. The interaction of rice husk biochar 10 tons ha$^{-1}$ and clay-soils 10 tons ha$^{-1}$ (P6) was able to increase levels of organic carbon after incubation, 2 times compared to control, increase the best water holding capacity after harvesting and decrease soil permeability 2.74 times of control. Cow dung treatment 60 tons ha$^{-1}$ and clay-soils 10 tons ha$^{-1}$ (P5) was able to provide the best soil porosity and cow dung treatment 60 tons ha$^{-1}$ and rice husk biochar 10 tons ha$^{-1}$ (P4) was able to increase soil aggregate stability, 1.87 times compared to controls. There is a strong correlation between soil moisture and aggregates stability and soil porosity, with an increase in aggregate and soil porosity will increase the value of soil moisture. There is a negative correlation between soil porosity and soil permeability, high soil porosity can hold more water so that it can reduce the permeability rate.

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