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Effectivity of bulrush (*Scirpus californicus*.) as a soil conditioner in increasing sandy and clay soil fertility

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Abstract. *Izzati M, Haryanti S, Hastuti RB. 2021. Effectivity of bulrush (*Scirpus californicus*) as a soil conditioner increasing sandy and clay soil fertility. Biodiversitas 22: 3423-3429.* Bullrush (*Scirpus californicus*) is a species of macrophytes that often populates lakesides. This aquatic plant was rarely studied and its use has not been explored yet. This study was carried out to determine the effects of soil conditioner made from bulrush on sandy and clay soil fertility. Collected bulrush from Rawa Pening lake was milled into a powder and used as a soil conditioner in a proportion of 1:1. After a week, soil fertility was evaluated including organic matter content, water retention, the ratio of C/N, and bacteria population. The study was designed using a Completely Randomized Design with two treatments and control. Resulted data were analyzed using a t-test to evaluate the difference between the two treatments. Results showed that bulrush powder application significantly increased sandy and clay soil fertility. The organic matter content significantly increased in both sandy (p<0,01) and clay soils (p<005). The water retention of sandy soil was increased by 74% (p<0,01), while in clay soil was reduced by 27% (p<0,01). The C/N ratio was significantly reduced in both sandy and clay soil (p<0,05), while the bacteria population significantly increased (p<0,01). It is suggested to use the bulrush as a soil conditioner particularly for sandy and clay soils.

Keywords: Bulrush, clay soil, conditioner, sandy soil

INTRODUCTION

Bulrush (*Scirpus californicus*) belongs to the family *Cyperaceae* and is one of the major sedge weeds that usually infest wetland paddy fields (Hakim et al. 2010). This invasive tropical perennial emergent aquatic plant has fibrous roots, triangular stems, and long leaves (Kendra et al. 2011). This macrophyte is found abundantly along the Rawa Pening Lake's side, located at Ambarawa district, Central Java, Indonesia. It can produce large quantities of green biomass and grows to a height of 1.5 to 2.5 m.

This aggressive weed spreads very fast and its removal is expensive. The removal through tillage or burning has only resulted in a short effect (Karthikeyan 2017). The abundant bulrush needs to be managed by removing and processing it into useful products. This plant is used to feed cattle, but its high heavy metal content has been assumed to enter into the food chain (Rajaganapathy et al. 2011). It has been found that this macrophyte is a metal accumulator and potential to be used for phytoremediation (Tangahu et al. 2011).

Hence, our study was undertaken to evaluate the possibility of using this weed for soil conditioners to increase sandy and clay soil fertility. These two types of soil are the marginal land that is widely distributed across the islands of Indonesia such as, Java, Sumatra, Flores, and Kalimantan (Iqbal 2020). Sandy soil is usually also distributed in the coastal areas and mountain valleys. The infertile marginal lands require a certain treatment to increase the capability of supporting plant growth.

Sandy soils are often considered to have a weak structure, poor water retention, and high water infiltration (Abu-Zreig et al. 2020). Therefore, nutrient leaching is also high (Minhal 2020). Clay soil on the other hand has a very small particle size, so its water retention is very high (Finch and Lane 2014). This type of soil has little oxygen around plant roots. Treatment with a soil conditioner may repair the fertility of sandy and clay soils. The addition of an organic soil conditioner will improve the physical, chemical, and biological properties of soil, including organic matter content, water retention, aeration, and microorganism population (Shinde et al. 2017).

As sandy soil has more macro-pores, water infiltrates easily and water retention is reduced. The addition of an organic soil conditioner such as bulrush powder increases the soil organic matter which will help to retain water. Meanwhile, the lack of macro-pores in clay soil will be repaired with the presence of organic matter. This will lead to an increase in water infiltration and provide more aeration that is crucial for plant root respiration. The increased amount of organic matter in the soil will change the C/N ratio as the organic matter has more Carbon and Nitrogen that depends on the type of organic material used as a soil conditioner. The organic matter in the soil also acts as a substrate for bacterial growth; therefore, an increase of organic matter will increase the population of bacteria in the soil.

MATERIALS AND METHODS

Area study

This study was conducted at Diponegoro University, Semarang, Indonesia The bulrush biomass was collected from Rawa Pening lake, Central Java, Indonesia. These aquatic plants were chosen due to their high population along the side of Rawa Pening lake. The plant was transported to the laboratory and the whole plant was washed and chopped into small pieces and dried under the sun. The dried bulrush biomass was then milled into powder using a milling machine into approximately 0.5mm of particle size. This powder was then used as a soil conditioner and applied on sandy and clay soils as a soil conditioner. The sandy soil used in this experiment was collected from the area around Mount Merapi valley (located at Magelang district, Central Java). The clay soil was taken from the nearby campus area of Diponegoro University. These two types of soil were studied because they have different characteristics and fertility. Both sandy and clay soils were also dried under the sun to eliminate the remaining water content in them. The study used a ratio of soil media to soil conditioner of 1:1. Each soil media and soil conditioner was mixed thoroughly to achieve evenly mixed media and soil conditioner. Four liters of treatment (mixed with each soil media and soil conditioner) were filled into a 5 liters- plastic pot.

Parameter observation

Measurement of soil fertility was done after a week (7 days). A small sample was taken from each treatment and replication, then brought to soil laboratories to be analyzed for their soil organic matter content, water retention, C/N ratio, and bacteria population. Soil organic matter was measured using the Walkley-Black method (FAO 2019) started with a sampling of 2 g dried soil, and then taken into a conical flask. Into each flask, 10 mL of 1N $K_2Cr_2O_7$ and 10 mL of H_2SO_4 were added, then mixed thoroughly with slight rotating and allowed to cool for 30 minutes. 3 mL diphenylamine is used as an indicator. Titration was done with $FeSO_4.7H_2O$ solution (1N). A blank titration was run to standardize the $FeSO_4.7H_2O$ solution against the standard $K_2Cr_2O_7$ solution.

Organic matter in the soil was calculated by carbon in the soil as the following formula:

Soil organic matter - 1.72X soil organic carbon

The bacteria population in the soil was measured using the dilution and plating method. A small sample of soil was serially diluted in water, then plated on agar within a Petri plate. A small amount of soil (1 mL) of the diluted soil suspension was spread over the surface of the nutrient (peptone yeast) agar plate to allow the growth of soil bacteria. The number of bacteria was calculated using the following formula:

The number of bacteria (CFU) per gram soil = 1/ Dilution factor (x number of colony form).

Measurement of the C/N ratio was conducted using the combustion method. Soil samples were combusted to analyze total carbon and nitrogen concentration on a Perkin-Elmer 2400 Series II CHNS/O Analyzer (Waltham, MA). Soil infiltration rate was tested using simple methods. It was started by pouring 300 mL of water into a 4 L plastic pot containing soil with a hole in the bottom of the pot. The period needed to infiltrate all of the water into the soil was recorded.

Soil water retention was measured by drying mixed soil media and soil conditioner under the sun to reach constant weight. Each 4kg of mixed soil was then placed into a plastic pot with a hole in the bottom. As much as 4 liters of water was poured into the soil in the pot and the water dropping out from this pot was collected in a plastic bowl. The volume of collected water was recorded to be used to calculate the percentage of water that a certain volume of soil can hold.

The calculation formula is as follows:

$$\text{Percentage of retained water} = \frac{\text{initial weight of water} - \text{the weight of dripped water}}{\text{The initial weight of Soil}} \text{ X } 100\ \%$$

This experiment was conducted using a completely randomized design (CRD). There were 2 treatments in this experiment, i.e: sandy soil media with bulrush powder and clay soil with bulrush powder. Sandy and clay soils alone without the addition of bulrush powder were used as controls. Every treatment was repeated 4 times. Collected data were analyzed using ANOVA, and t-test. The soil fertility measured were the soil physical, chemical, and biological properties.

RESULTS AND DISCUSSION

Soil organic matter

The soil organic matter between pure sandy and clay soil was significantly different (Figure 1). Clay soil alone already had a high content of soil organic matter (9.9139%), compared to sandy soil (0.38%). This difference was highly significant ($p<0.01$). Sandy soil has a relatively small organic matter content. According to Yost and Hartemink (2019), the soil organic matter content in sandy soil in Asia was 0.6%. Sandy soil used in this study is pure sand taken from the river closed to mount Merapi that is usually used for construction. This may explain why the content of soil organic matter is too small.

We found in this study that organic matter content in sandy soil before treatment was 0.38%, while clay soil was 9.91%. The study by Budiyanto et al (2020) showed similar results: sandy soil taken from Parangtritis at the south coast of Java island had soil organic matter of less than 0.55%. The soils in the United Arab Emirates are mostly sandy and lack sufficient organic matter to sustain microbial activity (Alshankiti and Gills 2016).

The clay soil used in this study had 24 times as much soil organic matter as sandy soil. The content of organic matter in clay soil was much higher compared to that in sandy soil. Haddad et al. (2018) studied a similar topic and found that organic matter in clay soil is more than 15 times compared to sandy soil. The source of soil may also affect the different levels of soil organic matter. The clay soil used in this study was taken from around the campus of Diponegoro University. This soil is rarely been used for cultivation. According to Batjes (2016), soil organic matter is affected by soil texture and soil particle size. Sandy soils consist of bigger particle sizes and have a limited capacity to stabilize organic compounds (Feng et al 2013). The clay fraction in the soil has smaller size particles and accumulates more organic matter (Jagadamma and Lal, 2010). Organic matter levels rise linearly with decreasing particle size content (Gao et al. 2014; Deng et al. 2017). Changes in soil organic matter stock are most closely related to the clay content (Zhong et al. 2018). Tahir and Maschner (2018) confirmed that clay addition to sandy soil increased soil organic carbon. The addition of clay-rich subsoil to sandy soil has been shown to increase crop production on sandy soils (Hall et al. 2010), mainly attributed to improved water and nutrient holding capacity.

The addition of bulrush powder as a soil conditioner significantly increased organic matter content in both sandy and clay soils (Figure 1). In sandy soil, the organic matter increased by 300%, while the increase was only 47% in clay soil. The difference is big presumably because the clay soil has already contained a high amount of organic matter, while sandy soil has a much lower content of organic matter.

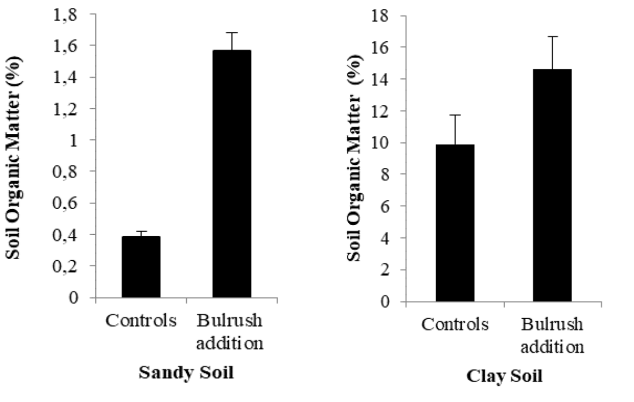
The study by El-Saied et al. (2014) showed similar results where the addition of soil conditioner from rice straw increased organic matter in sandy soil. According to Xu et al. (2016), different biotic and abiotic factors specifically affect soil organic matter dynamics. Accumulations of soil organic matter in heavy rainfall forest areas were shown to have been largely regulated by clay minerals (Xu et al. 2016). Soil organic matter dynamics also vary because of different vegetation types (Gruba et al. 2015; Saiz et al. 2012; Jin et al. 2013).

Soil organic matter reflects the long-term balance between plant carbon inputs and microbial decomposition (Torn et al. 2017). Soils are composed of solids (mineral and organic matter) and pores which hold air and water (Chaudhari, et al. 2013). Soil organic matter plays a central role in soil fertility (Torn et al. 2017), determining the soil physical, chemical, and biological properties (Signor et al. 2016).

Soil water retention

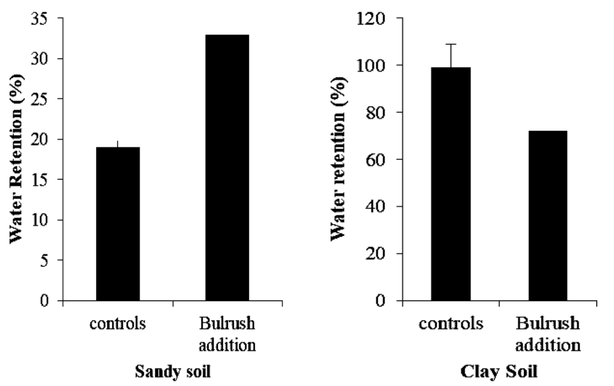
We found in this study that sandy soil alone retained water by 19%, while clay soil 99.2% (Figure 2). Application of bulrush powder to sandy soil increased water retention 74% higher than controls. On the other hand, in clay soil water retention was reduced to 27% compared to controls. This strongly indicated that the addition of organic soil conditioners on different soil textures significantly affected water retention differently.

According to Amooh and Bonsu (2015), the single most important property of soil that determines water retention is the soil texture. We found from this study that the effect of organic soil conditioners on water retention depends on soil textures. The presence of organic soil conditioner on sandy soil texture increased water retention significantly. The study by Darusman et al. (2018) showed similar results where the addition of organic as soil conditioner increased water retention of dry land. Similar results have also been reported by Djajadi et al. (2011) that applying organic matter into sandy soil increased water retention. According to Xu et al. (2019), the application of manure in sandy soil decreases macropores but increases micropores. Hence, water retention will be increased. Djajadi et al. (2011), also reported that the addition of compost significantly increased soil water retention in sandy soil. The application of biochar on sandy soil also enhances water retention (Alotaibi and Schoenau 2019).



A B

Figure 1. The Soil Organic Matter Content Among Treatments. Soil conditioners from bulrush powder increase organic matter in sandy (A; p<0.01), and clay soil (B; p<0.05). The different lower cases indicate significant differences. Error bars represent the standard error of the mean



A B

Figure 2. Water retention differences among treatments. The addition of bulrush powder increased (74%) water retention and sandy soil (A), but reduced (27%) water retention in clay soil (B). The differences were all highly significant (p<0.01). Different lower cases indicate significant differences. Error bars represent the standard error of the mean.

To support plant growth, the sandy soil requires substantial efforts (Amooh and Bonsu 2015). Arthur et al. (2012) stated that to sustain crop production sandy soils with low productivity could be improved by compost application of soil amendments. Without soil amendments, the sandy soil will lack moisture and will reduce plant growth. In this study, the application of bulrush powder as a soil conditioner also significantly improved sandy soil fertility through increasing water retention.

In contrast to sandy soil, the addition of soil conditioner from bulrush powder resulted in a decrease in water retention in clay soil. According to Obia (2018), clay soil has poor aeration and drainage, therefore water retention is too high and needs to be reduced to allow soil aeration. Organic matter influences many soil characteristics including, aeration and workability (Chaudari et al. 2013). The presence of a soil conditioner made from bulrush helps clay soil to increase aeration as porosity is increased, therefore water infiltration will be improved. In such a case, the particle size of the soil conditioner should be bigger than the clay particle size. Therefore, it can be used to create more macropores for soil aeration.

Soil porosity is the gap among solid particles, which contain water and air. The degree of porosity depends on particle size (Zhang and Tsang 2019). Porosity is significantly higher in larger particles (Taleghani et al. 2015). Clay soil has tiny particles and more micropores, and therefore, tends to retain water but exclude air (Amooh and Bonsu 2015). As a result, clay soils are prone to drain poorly and become waterlogged. Soils with high organic matter have high porosity, and therefore, the infiltration rate is also high (Darusman et al. 2018). Soil porosity will increase soil oxygen and help root respiration. Holding too much water will eliminate soil oxygen and root respiration will be limited. Therefore, plants need both water and oxygen at the same time.

This study showed that the application of bulrush powder as a soil conditioner increased soil fertility of sandy and clay soils. Water retention of sandy soil was increased, while in clay soil reduced. The suitability of soil as a plant growth medium depends not only on the presence and quantity of chemical nutrients but also on the state and movement of water and air (Amooh and Bonsu 2015).

The ideal soil would hold sufficient air and water to meet the needs of plants with enough pore space for easy root penetration, while the mineral soil particles would provide physical support and plant essential nutrients (Chaudhari et al. 2013). Loamy soil has both sand and clay, so it has macropores and micropores giving a more balanced supply of both air and water.

Water retention in the soil is one of the most important factors of soil fertility (Zhang and Tsang 2019). Soil water content is strongly dependent on soil texture (Amooh and Bonsu 2015: Ghezzehei et al. 2018). Sandy soils are considered poor in water retention. According to Amooh and Bonsu (2015), sandy soils are dry and have larger pores that hold air but not water, and allow the water to drain freely. Therefore, in sandy soil water shortage always occurs which is a key factor limiting crop production (Zhang and Han 2019).

Soils with a substantial amount of organic matter have good water retention and support plant growth by making soil moisture available to the crops (Amooh and Bonsu 2015). Organic matter is the key to drought-resistant soil and sustainable food production (Tahat et al. 2020). Organic matter is effective in most situations for conserving soil water (Gloria and Katan 2020).

C/N ratio of soil

There was a significant difference in the C/N ratio between the controls of sandy and clay soils. C/N ratio in clay soil was 292.3, while in sandy soil was 38.26 (Figure 3). Tropical sandy soil, which has low organic matter, tends to have a low potential for C and N storage (Arunrat et al. 2020). The capacity of sandy soil particles to preserve organic matter is smaller than clay soil (Hamarashid 2010).

The high value of the C/N ratio in clay soil is an indication that the soil has much more carbon than nitrogen. In such conditions, the soil is not in mature condition yet. Therefore, only a small portion of the nitrogen is available. In this study, the clay soil was taken from the area around the campus of Diponegoro University that has never been used for agriculture. Clay soil typically has a high C/N ratio (Swangjang 2015). According to Akortia et al. (2019), organic carbon content increased with diminishing particle size. This means that the smaller particle size in clay soil will increase organic carbon and the C/N ratio will be high. Hook and Burke (2020) concluded that the soil C/N ratio has a strong correlation with soil texture.

The C/N ratio can be controlled by the addition of organic matter (Akratos et al. 2017). This addition can either lower or increase the C/N ratio, depending on the material type added. For example, the addition of high nitrogen organic material will lower the C/N ratio, while the low nitrogen content and high organic carbon will result in a higher C/N ratio.

This study showed that the addition of bulrush powder as a soil conditioner lowered the C/N ratio in sandy and clay soils. The C/N ratio was reduced by 53% in sandy soil, while in clay soil 82%. This is an indication of increasing nitrogen concentration in both sandy and clay soils. According to Park et al. (2019), the addition of green material or animal manure usually will result in a smaller C/N ratio. The decrease in the C/N ratio is observed due to the release of organic matter content during the composting process. Residues with higher C/ N ratios such as corn and wheat may decompose slower than residues with lower C/N ratios, such as legumes (Blanco-Canqui 2015). C/N ratio is an expression of the most important properties that indicate the nitrogen concentration of the organic materials added into the soil (Truong and Marschner, 2018). A smaller C/N ratio of sandy soil treated by rice straw-based hydrogel has also been found in the study of El-Saied (2014).

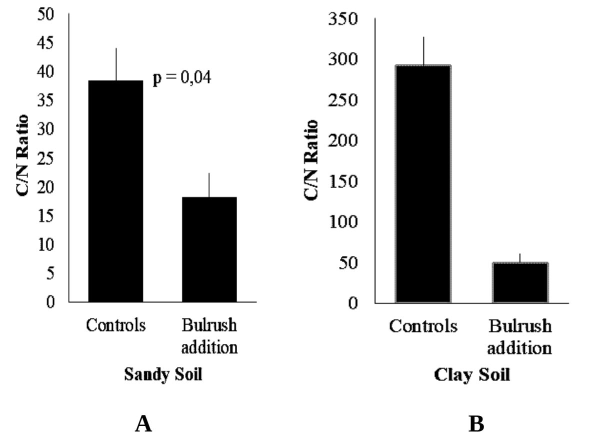


Figure 3. Application of bulrush powder reduced C/N ratio of sandy soil (A; 53%), and clay soil (B; 82%). The difference was significant (p<0,05). Note: the different lower cases indicate significant differences. Error bars represent the standard error of the mean

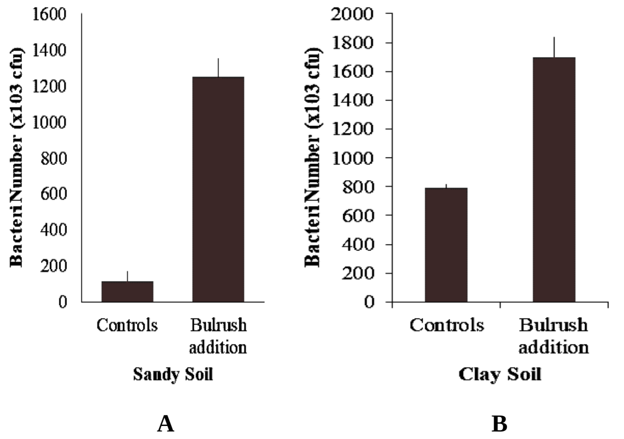


Figure 4. Application of bulrush powder significantly increases bacteria number of sandy (A) and clay (B) soils. The different lower cases indicate significant differences. Error bars represent the standard error of the mean

We hypothesized that the decrease of the C/N ratio by application of bulrush powder as soil conditioner was probably caused by the high content of nitrogen in the bulrush biomass. Bulrush is an aquatic macrophyte that contains high nitrogen. It has been studied by Karthikeyan et al. (2017), that bulrush contains nitrogen- around 56%. This might explain why the addition of bulrush powder into sandy and clay soils significantly reduced the C/N ratio. The reduction of the C/N ratio is an indication that the nitrogen availability in the soil is increased. According to Akratos et al. (2017), the C/N ratio indicates the rate of decomposition of organic matter and soil nitrogen availability for the plants. The C/N ratio is significant in composting because microorganisms need a good balance of carbon and to remain active (Akratos et al. 2017). The C/N ratio is an indication of the carbon and nitrogen balance in soils (Ge et al. 2013). It is a sensitive indicator of soil quality.

Soil bacteria population

We found in this study that clay soil significantly has more bacteria population compared to sandy soil (p<0,05). According to Hemkemeyer et al. (2018), clay soil has a more microbial population because of its smaller particle size. Smaller size particles will retain more water and soil moisture will increase microbial population and activity (Borowik and Wyszkowska, 2016). Soil particle size represents distinct microenvironments that support bacteria growth rate (Hemkemeyer, 2018). A higher bacteria population in clay soil is also due to a higher accumulation of organic matter (Hamarashid, 2010). Results from this study also showed that clay soil has more organic matter and water retention. This may explain the higher than clay soil has more bacteria population.

The application of soil conditioner from bulrush powder significantly increased bacteria population in both sandy and clay soils (p<0.05) (Figure 4). The higher amount of organic matter after the addition of bulrush powder may explain this phenomenon. The presence of bulrush powder provides more organic matter and water retention will be increased. In such conditions, it will be a good medium for bacteria to grow. Soil microorganisms play an important role in soil fertility by recycling essential plant nutrients through decomposition (Haddad et al. 2019). Microbial metabolism accelerates the decomposition of organic matter, promotes the mineralization of nutrients, and stimulates nutrients absorbed by plants (Li et al. 2017). Soil texture plays a key role in carbon storage and strongly influences nutrient retention and availability (Hamarashid 2010). Plant-bacterial interactions in the rhizosphere are the determinants of plant health and soil fertility (Hayat 2010).

This study concluded that the application of bulrush powder increased the fertility of sandy and clay soils. Therefore, we recommend that bulrush powder be used as a soil conditioner, particularly for sandy and clay soils.

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