*Soil Environ. 40(1): 49-58, 2021*
*DOI:10.25252/SE/2021/182443*
*Online ISSN: 2075-1141*
*Print ISSN: 2074-9546*

# Improving physical characteristics of a sandy soil by adding mycorrhizae and soil amendments

***Aktavia Herawati*, Mujiyo Mujiyo, Jauhari Syamsiyah, Sani Kamil Baldan, and Noviawati Maulani Wulangsari***
Department of Soil Science, Faculty of Agriculture, Universitas Sebelas Maret,
Jl. Ir. Sutami 36 A, Kentingan, Surakarta, 57126, Indonesia
***[Received:** July 11, 2020* ***Accepted:** March 19, 2021* ***Published Online:** May 28, 2021]*

## Abstract

*Sandy soil has certain limitations such as low water holding capacity, high infiltration, high evaporation, and low soil moisture. To solve these problems, the addition of mycorrhizae and soil amendments to sandy soil could be able to improve the limitation. This study aimed to determine the effect of mycorrhizae and soil amendments on physical characteristics of sandy soil. The experiments were arranged using the CRD (Complete randomized design) method with two factors: doses of mycorrhizael and types of soil amendments. Doses of mycorrhizae consist of M0 (without mycorrhizae), M1 (mycorrhizae 3 spores pot$^{-1}$), and M2 (mycorrhizae with 6 spores pot$^{-1}$). The types of soil amendments consist of A0 (control), A1 (cow manure), A2 (biochar), A3 (clay soil), A4 (cow manure-biochar), A5 (cow manure-clay soil), A6 (biochar-clay soil). The results showed that mycorrhizae with cow manure-clay soil (M1A6) maintained the average of soil moisture seven days after harvest with an average of 12.65% and also reduced the rate of soil permeability three times than control. The combination of biochar-clay soil and mycorrhizae improved the water holding capacity and soil aggregation. Interaction of mycorrhizae and soil amendments improved the physical characteristics of sandy soil by increasing soil moisture and reducing soil permeability.*

**Keywords:** Sandy soil, biochar, mycorrhizae, soil aggregate, soil permeability

## Introduction

Indonesia has sandy soil covering 52.37 million hectares, an alternative agricultural land to overcome land conversion (Dariah *et al*., 2010; Riptanti *et al*., 2018). Cultivation of plants in sandy soil needs to be continuously developed, but there are many obstacles such as drought and low nutrient availability, which causes plants to die (Liu *et al*., 2017). Sandy soil has low soil fertility; low water retention capacity, high infiltration, low organic matter, and low soil moisture so that it is less productive for plant growth (Rusli *et al*., 2016; Xu *et al*., 2016). Therefore, it is necessary to make improvements to reduce growth-inhibiting factors, including the provision of mycorrhizae and soil amendments.

The application of mycorrhizae in sandy soils can defend plants from drought (Constantino *et al*., 2008), experiencing damage to cortical tissue. Mycorrhizae fungi are symbiotic with roots on host plants and produce fungal hyphae, which can absorb water in the soil pores when plant roots are no longer able to absorb water (Solaiman & Hirata, 1995). Large hyphae cause increased water absorption and soil does not dry out easily (Rusli *et al*., 2016).

Rice husk is the primary agricultural residue that accounts for 731 million tons per year globally (Park *et al*., 2014). About 25% of the rice husk is burnt during the harvest season, damaging air quality, and human health (Xu *et al*., 2016). Biochar from rice husk can improve sandy soil pores. Biochar particles can replace macropores into micropores, which increase water retention (Tang *et al*., 2013). Cow manure with a potential of 345.7 thousand tons per day is used as organic waste to increase aggregation and plant growth (Dariah *et al*., 2010; Rahayu *et al*., 2020; Zhou *et al*., 2020). Clay soil can be used as a soil amendment to increase soil aggregation and water holding capacity. So, the application of mycorrhizae, biochar rice husk, cow manure, and clay soil can improve physical characteristics of sandy soil.

The previous research in sandy soil about mycorrhizae interaction with various soil amendments has not been widely carried out; only report the one effect of them ( Constantino *et al.*, 2008; Abel *et al*., 2013; Pu *et al*., 2019;

*Email: aktavia_h@staff.uns.ac.id

Rahayu *et al.*, 2019). Based on previous research, mycorrhizae and soil amendments interaction has a significant effect on improving sandy soil characteristics. This study aimed to determine the effect of mycorrhizae and soil amendments on physical characteristics of sandy soil. Mycorrhizae and soil amendments are expected to increase water availability by increasing water holding capacity, reducing infiltration rates, and soil permeability. The novelty was mycorrhizae's interaction with various soil amendments (a combination of cow manure, biochar, and clay soil) in sandy soils. Mycorrhizae and soil amendments are expected to be a solution in fixing the problem of sandy soil characteristics.

## Materials and Methods

### Research design

The research was conducted at the Screen House, Faculty of Agriculture, Sebelas Maret University, located in Sukosari Village, Jumantono District, Karanganyar Regency, Indonesia. This study was arranged using a completely randomized design (CRD), consisting of two factors. The first factor was doses of mycorrhizae, M0 (without mycorrhizae), M1 (mycorrhizae 3 spores pot$^{-1}$), M2 (mycorrhizae 6 spores pot$^{-1}$) (Syamsiyah *et al*., 2014). The type of used mycorrhizae was endomycorrhizae, namely Arbuscular Mycorrhizae Fungi. Measuring spore density by wet filtering, decantation, centrifugation, and filtering to separate the spores; and found that every 50 of mycorrhizae contained 30 spores, meaning that every 5, had been an average of 3 spores.

The second factor was types of soil amendment: A0 (without amendment), A1 (cow manure 60 ton ha$^{-1}$) (Prasetyo, 2014), A2 (biochar 25 ton ha$^{-1}$), A3 (clay soil 10 ton ha$^{-1}$), A4 (cow manure 60 ton ha-1 and biochar 25 ton ha$^{-1}$), A5 (cow manure 60 ton ha$^{-1}$ and clay soil 10 ton ha$^{-1}$), and A6 (biochar 25 ton ha$^{-1}$ and clay soil 10 ton ha$^{-1}$). So that obtained 21 treatment combinations and repeated three times to avoid the subjectivity of the treatment data. The total sample population was 63 units of experimental pots. Basal fertilizer (NPK 15-15-15) was applied at doses of 100 kg ha$^{-1}$ to all treatments two weeks after planting.

### Initial analysis of sandy soil and soil amendments

The results of the initial sandy soil analysis are as follows: water content, 0.45%; soil pH, $H_2O$ (1:2.5), 7.12; organic carbon, 0.18%; C/N ratio, 14.34; bulk density, 1.85 g cm$^{-3}$; particle density, 2.9 g cm$^{-3}$; soil permeability, 1210 cm hour$^{-1}$; aggregate stability index 0; soil texture (sand 92.23%; silt 6.81% and clay 0.96%) (Table. 1). Sandy soil had a low soil physical and chemical fertility, organic carbon values, moisture content, permeability, aggregate stability, and texture was not supportive for plants (Pu et al., 2019).

The cow manure was composted and had a dark black color, loose texture, not sticky, cold temperature, and odourless ness. The characterictics of cow manure: moisture content, 26.96%, pH $H_2O$ (1:5), 7.88, organic carbon, 16.62% and C/N ratio, 26.39 (Table 1). The characteristics of rice husk biochar: moisture content, 8.11%; pH $H_2O$, (1:5), 6.14; organic carbon, 18.07%; and C/N ratio, 33.3 (Table 1). The characteristics of clay-soil: moisture content, 0.58%; pH $H_2O$ (1:2.5), 7.1; organic carbon, 2.13%; and C/N ratio, 10.7; and soil texture (sand 8%, silt 43%, and clay 49%) (Table 1).

**Table 1. The initial characteristic of soil, cow manure, rice husk biochar and clay soil**

| Parameter | Unit | Value | | | |
|---|---|---|---|---|---|
| | | Soil | Cow manure | Rice husk biochar | Clay-soil |
| pH $H_2O$ | - | 7.12 (1:2.5) | 7.88 (1:5) | 6.14 (1:5) | 7.1 (1:2.5) |
| Organic carbon | (%) | 0.18 | 16.62 | 18.07 | 2.13 |
| Total-N | (%) | 0.015 | 0.634 | 0.541 | 0.202 |
| C/N ratio | - | 14.34 | 26.39 | 33.33 | 10.7 |
| Bulk density | g cm$^{-3}$ | 1.85 | - | | - |
| Particle density | g cm$^{-3}$ | 2.9 | - | | - |
| Soil permeability | cm hour$^{-1}$ | 1210 | - | | - |
| Texture | | | | | |
| - Sand | (%) | 92.23 | | | 8 |
| - Silt | (%) | 6.81 | | | 43 |
| - Clay | (%) | 0.96 | | | 49 |

### Incubation and mycorrhizae applications

The soil was taken from topsoil (0-20cm) at sandy beach in Bantul Regency, Yogyakarta Province, then sieved with a

2 mm sieve to separate the soil fraction from the rock. Soil weighing 10 kg was put into a polybag, then mixed with soil amendments according to the treatment, then incubated for four weeks. After an incubation period, mycorrhizae was applied right to the planting hole. The plant roots could become infected because mycorrhizae were obligate symbols that were active when in direct contact with the host plant roots. Planting the seedlings of chili was carried out simultaneously with the mycorrhizae application. The chili seeds were transplanted at the age of one month with an average height of 15 cm, with the seeds being not too old because old seeds tend to have rigid cell walls so that the germinated mycorrhizae spores become difficult to infect plants root tissue. Maintenance included watering and removing weeds until the maximum vegetative period (110 days after planting/dap).

## Observation parameters

The measurement of soil moisture was done every week until harvest (110 dap). Soil sampling was carried out a week after harvest. Soil samples were taken at a depth of 0-20 cm and analyzed for several physical characteristics: daily soil moisture seven days after harvest using the gravimetric method, soil aggregate stability using the wet shear method (Amézketa, 1999), soil permeability with the constant head permeameter method, and soil porosity. Measurement of water content for seven days aimed to determine the best treatment in maintaining soil moisture (Sohi *et al.*, 2010; Zhang *et al.*, 2020). Plant analysis included plant height, plant weight, root weight, root volume, and chili yield. Measurement of plant height every 1 week, measuring the yield when the chilies are ripe and accumulated until the end of harvest, while fresh weight, root weight and root volume are carried out at harvest (110 dap).

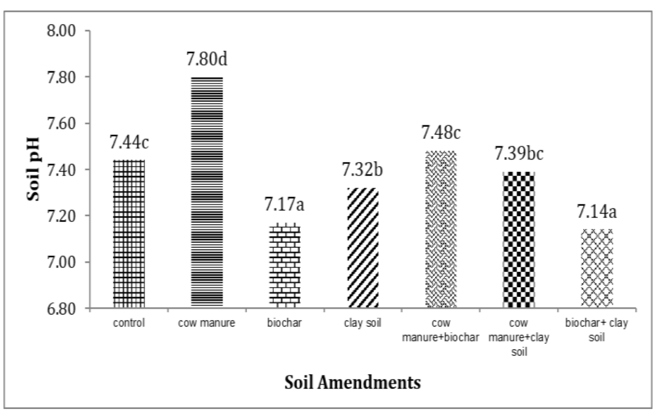


**Figure 1. The effect of soil amendments on soil pH after incubation**

Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test (α = 0.05)

## Statistical analysis

Data analysis was performed using Minitab.16 and Microsoft Excel 10 software. The statistical analysis used was Analysis of Variance (ANOVA) with a 95% confidence level to determine treatment/variables' effect. If the effect was significant, continued with the Multiple Distance Test (TUKEY) with a 95% confidence level to find a real difference and the Pearson correlation test to determine the relationship between variables.

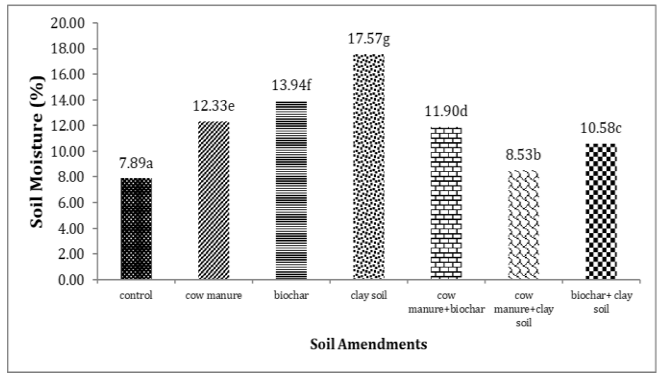


**Figure 2. The effect of soil amendments on soil moisture after incubation**

Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test (α = 0.05)

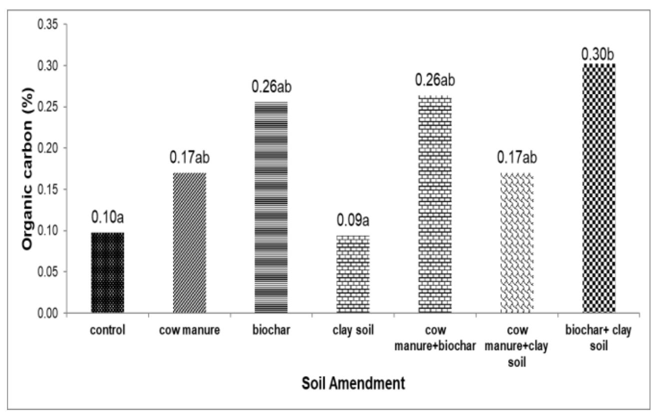


**Figure 3. The effect of soil amendments on soil organic carbon after incubation**

Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test (α = 0.05).

## Results

## Soil characteristic after incubation

Soil analysis was carried out to determine soil reactions between soil amendments during the incubation period. The application of soil amendments significantly increased the soil pH ($p \leq 0.01$) and soil moisture ($p \leq 0.01$) during the incubation period. The highest soil pH (7.80) was observed in cow manure's amendment treatment (Figure 1), and the highest soil moisture (17.57%) was recorded in the clay soil treatment (A3), 122.69% increase than control (Figure 2). The effect of soil amendments on organic carbon was not statistically significant ($p$>0.05), but the interaction of biochar with clay soil (A6) was the highest (Figure 3).

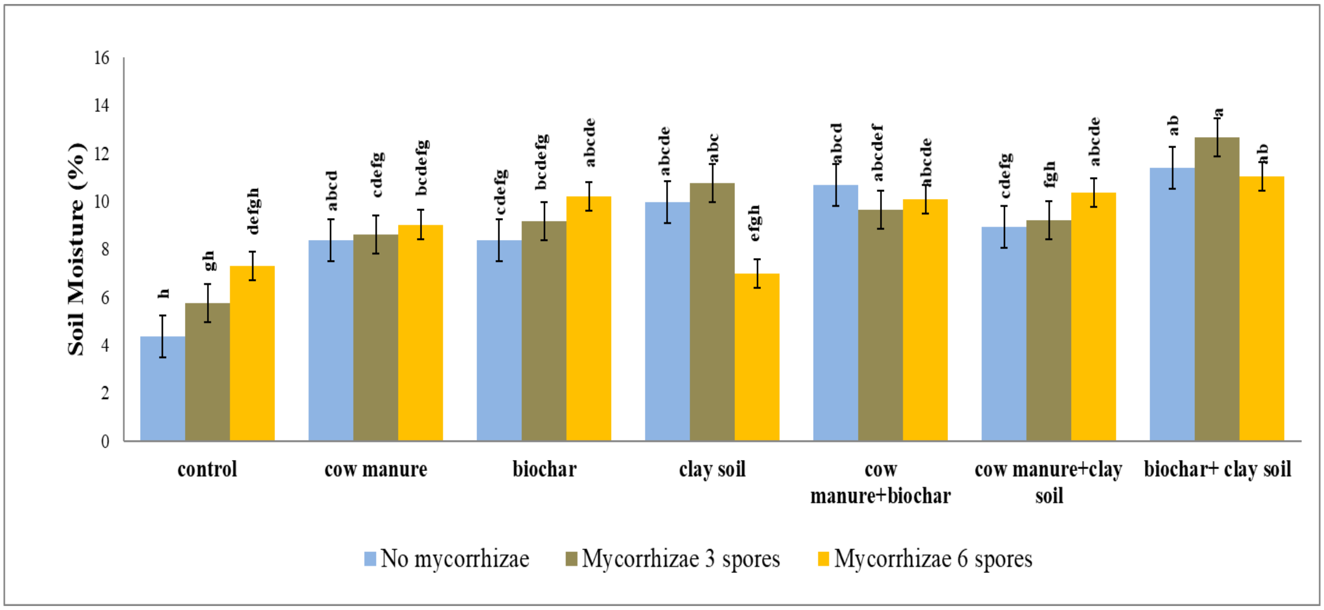


**Figure 4. The effect of mycorrhizae and soil amendments on soil moisture average a week after harvesting**
Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test (α = 0.05)

**Table 2. The effect of mycorrhizae and soil amendments on maintaining soil moisture a week after harvesting**

| Treatment | | Soil Moisture (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Average |
| No mycorrhizae | Control | 14.81 | 7.12 | 4.74 | 2.04 | 1.32 | 0.34 | 0.11 | 4.35 |
| | Cow manure | 27.60 | 14.72 | 12.81 | 9.59 | 8.92 | 7.94 | 5.07 | 12.38 |
| | Biochar | 19.05 | 11.21 | 8.52 | 6.30 | 5.41 | 4.43 | 3.63 | 8.36 |
| | Clay-soil | 19.62 | 13.00 | 9.98 | 7.77 | 7.20 | 6.22 | 5.99 | 9.97 |
| | Cow manure+Biochar | 21.03 | 13.62 | 10.74 | 8.49 | 7.82 | 6.84 | 6.28 | 10.69 |
| | Cow manure+Clay-soil | 19.80 | 12.29 | 7.87 | 5.59 | 6.49 | 5.51 | 4.95 | 8.93 |
| | Biochar+Clay-soil | 17.55 | 13.60 | 7.84 | 5.59 | 7.80 | 6.82 | 6.58 | 9.40 |
| Mycorrhizae 3 spores/pot | Control | 15.79 | 9.00 | 5.67 | 3.45 | 3.20 | 2.22 | 0.98 | 5.76 |
| | Cow manure | 20.42 | 12.35 | 6.60 | 4.40 | 6.55 | 5.57 | 4.30 | 8.60 |
| | Biochar | 19.72 | 12.25 | 8.78 | 6.55 | 6.45 | 5.47 | 4.89 | 9.16 |
| | Clay-soil | 21.50 | 14.91 | 11.48 | 9.29 | 9.11 | 8.13 | 7.89 | 11.76 |
| | Cow manure+Biochar | 19.65 | 13.18 | 8.69 | 6.45 | 7.38 | 6.40 | 5.84 | 9.65 |
| | Cow manure+Clay-soil | 19.55 | 12.28 | 8.94 | 6.73 | 6.48 | 5.50 | 4.94 | 9.20 |
| | Biochar+Clay-soil | 19.42 | 15.28 | 14.94 | 12.68 | 9.48 | 8.50 | 8.26 | 12.65 |
| Mycorrhizae 6 spores/pot | Control | 17.21 | 9.91 | 8.16 | 5.96 | 4.11 | 3.13 | 2.57 | 7.29 |
| | Cow manure | 21.25 | 11.60 | 8.87 | 6.61 | 5.80 | 4.82 | 4.26 | 9.03 |
| | Biochar | 16.69 | 13.13 | 12.46 | 9.78 | 7.33 | 6.35 | 5.79 | 10.22 |
| | Clay-soil | 18.33 | 9.69 | 6.93 | 4.74 | 3.89 | 2.91 | 2.35 | 6.98 |
| | Cow manure+Biochar | 20.88 | 12.69 | 10.50 | 8.27 | 6.89 | 5.91 | 5.35 | 10.07 |
| | Cow manure+Clay-soil | 23.13 | 13.94 | 7.99 | 5.71 | 8.14 | 7.16 | 6.60 | 10.38 |
| | Biochar+Clay-soil | 17.65 | 13.93 | 10.43 | 8.18 | 8.13 | 7.15 | 6.92 | 10.34 |

## Soil moisture a week after harvesting

Measurement of soil moisture was carried out using the gravimetric method, done every day for one week after harvest without re-watering. The measurement of soil moisture for seven days was aimed to determine the best treatment in maintaining soil moisture. Interaction of moisture. There was a phase of decreasing water content on the first - four days and was constant on the fifth - seventh days (Figure 5). Application of mycorrhizae (6 spores pot$^{-1}$) with biochar-clay soil (M2A6) had a soil moisture average of 6.92%, without mycorrhizae with biochar-clay soil (M0A6) 5.58% and 0.11% (M0A0) for control.

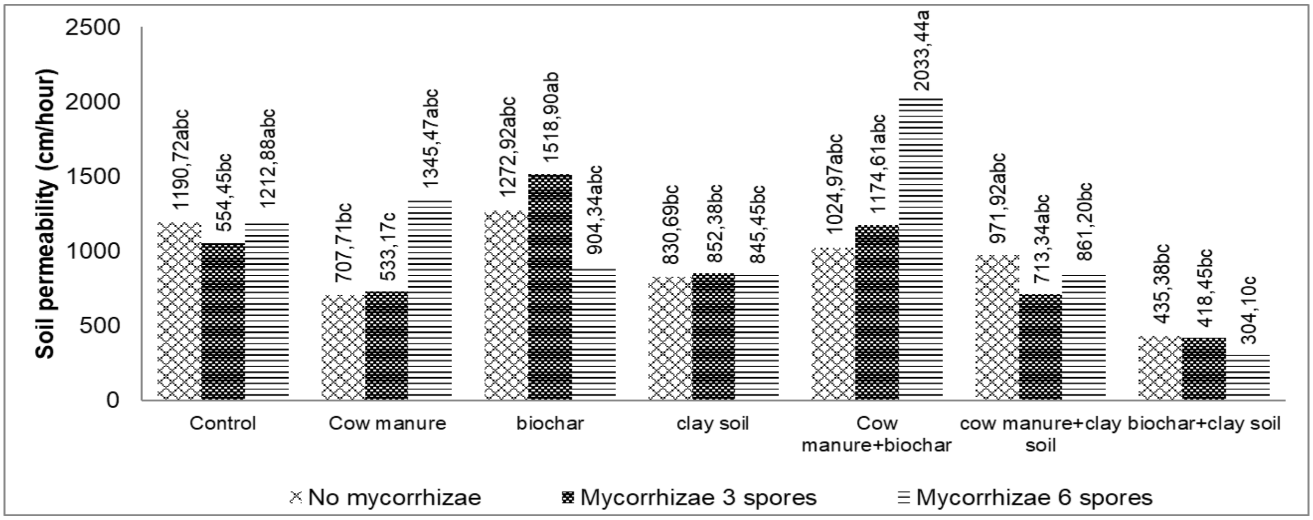


**Figure 5. The effect of mycorrhizae and soil amendments on soil permeability**
Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test (α = 0.05)

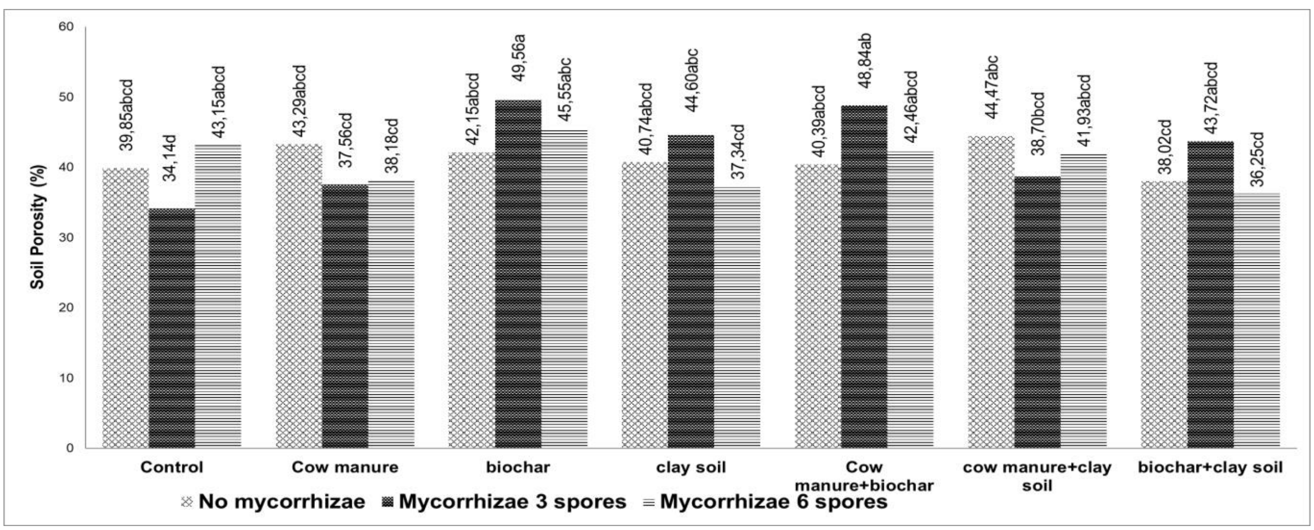


**Figure 6. The effect of mycorrhizae and soil amendments on soil porosity**
Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test (α = 0.05)

mycorrhizae and soil amendments had a significant effect on the average soil moisture ($p \leq 0.05$). The mycorrhizae three spores pot$^{-1}$ and biochar-clay soil (M1A6) were the highest soil moisture average (12.65%) that was 2.9 times higher than the control (M0A0) (Figure 4). Mycorrhizae and biochar-clay soil was the best treatment to conserve the soil

## Soil permeability after harvesting

Sandy soil has very high permeability (n> 25) and quickly releases water to the soil depth. Adding clay soil to sandy soil is expected to increase aggregation to reduce the permeability of sandy soil. Application of mycorrhizae (6 spores pot$^{-1}$) and biochar-clay (M2A6) reduced the rate of soil permeability value up to 304.1 cm hour$^{-1}$, which decreased 3.9 times than control (1210 cm hour$^{-1}$) (Figure 6).

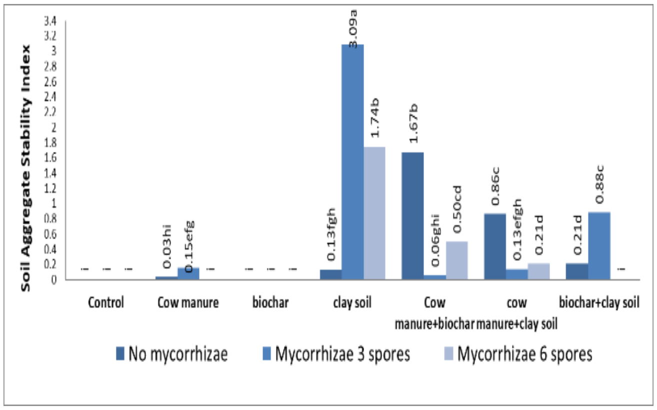


**Figure 7. The effect of mycorrhizaee and soil amendments on soil aggregate stability index**

Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test (α = 0.05).

## Soil porosity after harvesting

Interaction of mycorrhizae and soil amendments had a significant effect on soil porosity ($p \leq 0.05$), mycorrhizae spores three pot$^{-1}$ and biochar (M1A2) was the highest soil porosity (49.56%), increase 1.27 times than control (M0A0) (Figure 7).

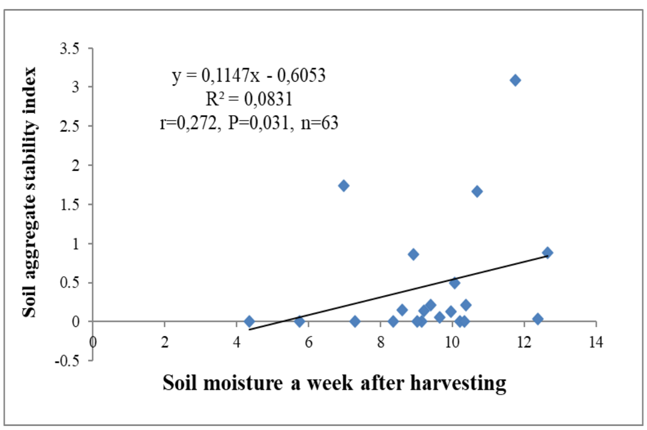


**Figure 8. Correlation between soil moisture a week after harvest and soil aggregate stability index**

## Soil aggregate stability index after harvesting

Interaction of mycorrhizae and soil amendments had a significant effect on soil aggregate stability index ($p \leq 0.05$). The highest occurred at mycorrhizae (3 spores pot$^{-1}$) and clay soil (M1A3), the index was 3.09 and 3 times higher than the control (M0A0) (Figure 8). The aggregate stability value above is included in the unstable class (index value > 40).

## The agronomic performance of chili at harvesting

Interaction of mycorrhizaee and soil amendments had a significant effect on plant height, plant height, root height, root volume and yield ($p \leq 0.01$). The highest occurred at mycorrhizaee (6 spores pot-1) and cow manure-clay soil (M2A5), (Table 3).

## Discussion

## Relationships between soil moisture, soil permeability, soil porosity, and soil aggregate stability

Clay soil increases soil moisture by 17.59%, a significant increase of 122.69% compared to the control. In line with previous research, adding clay soil can increase groundwater and water content's retention capacity in sandy soils due to the high plasticity between particles. The increasing of soil moisture is due to water holding in the soil, the side effect of increasing soil porosity, soil aggregate, and decreasing soil permeability (Rusli *et al*., 2016; Sika, 2012; Widiyawati *et al*., 2016). Added rice husks biochar affected on increasing water retention (Kammann *et al*., 2012), increasing carbon deposits in the soil (Lehmann, 2007; Wang *et al*., 2017), improving the physical, chemical and biological characteristics of the soil (Taek, 2016; Tang *et al*., 2013; Dewi *et al*., 2018) and mainly when applied to sandy soil (M. Zhang *et al*., 2017). Rahayu *et al*., (2019) reported that the application of biochar 5 tons ha$^{-1}$ was the highest result of shallot in sandy soil and increased soil fertility in the post gold mining land (Sulakhudin *et al*., 2017). It is right that the application of biochar and clay soil can reduce the rate of infiltration, resist evaporation and increase water retention in soil particles. The combination of biochar-clay soil increases the volume between soil pores because the elongated form of biochar particles will replace macropores into micropores available for water storage. The application of biochar increases the activity of *Mycorrhizael Helper Bacteria* (MHB). Biochar neutralizes allelochemicals around the roots and increases the activity of soil biology and mycorrhizae hyphae when colonized in roots (Bai *et al*., 2002; Constantino *et al*., 2008) so that the hyphae relationship mushrooms with roots can absorb more water (Santana *et al*., 2019). The increase in water uptake is caused by the interaction of mycorrhizae with soil amendments, where the external mycorrhizae cause *Arbuscular Mycorrhizael Fungi* (AMF) to work effectively in aggregating soil grains to form soil aggregates and increase the ability of the soil to hold water (Astiko *et al*., 2013). Mycorrhizae plays a role in the availability of glomalin (GRSP) produced by arbuscular mycorrhizae at the soil. This increase was due to the plasticity of clay soil, which increased the cohesion between soil particles.

**Table 3. The effect of mycorrhizae and soil amendments on agronomic performance of chili at harvesting**

| Treatment | | Plant height (cm) | Plant weight (g plant$^{-1}$) | Root weight (g plant$^{-1}$) | Root volume (ml) | Yield (g plant$^{-1}$) |
|---|---|---|---|---|---|---|
| No mycorrhizae | Control | 30.00$^{i}$ | 12.67$^{j}$ | 8.00$^{c}$ | 9.00$^{bc}$ | 32.03$^{j}$ |
| | Cow manure | 31.00$^{hi}$ | 19.00$^{ghi}$ | 6.33$^{c}$ | 11.00$^{abc}$ | 21.57$^{m}$ |
| | Biochar | 31.00$^{hi}$ | 15.33$^{i}$ | 5.67$^{c}$ | 5.00$^{c}$ | 19.40$^{n}$ |
| | Clay-soil | 33.33$^{fghi}$ | 18.33$^{hi}$ | 5.67$^{c}$ | 5.00$^{c}$ | 9.63$^{o}$ |
| | Cow manure+Biochar | 34.67$^{defg}$ | 29.67$^{cd}$ | 9.67$^{bc}$ | 12.67$^{abc}$ | 42.53$^{de}$ |
| | Cow manure+Clay-soil | 37.33$^{abc}$ | 38.33$^{b}$ | 10.67$^{bc}$ | 13.33$^{ab}$ | 56.67$^{b}$ |
| | Biochar+Clay-soil | 38.67$^{abc}$ | 37.00$^{b}$ | 13.33$^{b}$ | 10.00$^{bc}$ | 30.93$^{j}$ |
| Mycorrhizae 3 spores pot$^{-1}$ | Control | 33.00$^{fghi}$ | 12.00$^{i}$ | 9.00$^{bc}$ | 9.33$^{bc}$ | 33.23$^{i}$ |
| | Cow manure | 32.67$^{ghi}$ | 20.33$^{ghi}$ | 10.00$^{bc}$ | 17.33$^{ab}$ | 40.87$^{fg}$ |
| | Biochar | 32.33$^{ghi}$ | 24.67$^{ef}$ | 9.33$^{bc}$ | 9.67$^{bc}$ | 31.80$^{j}$ |
| | Clay-soil | 33.67$^{fgh}$ | 27.33$^{de}$ | 6.67$^{c}$ | 9.00$^{bc}$ | 41.40$^{ef}$ |
| | Cow manure+Biochar | 31.83$^{ghi}$ | 19.33$^{ghi}$ | 6.33$^{c}$ | 12.33$^{abc}$ | 23.07$^{l}$ |
| | Cow manure+Clay-soil | 38.00$^{abc}$ | 27.67$^{de}$ | 6.33$^{c}$ | 12.00$^{abc}$ | 43.63$^{d}$ |
| | Biochar+Clay-soil | 33.67$^{fgh}$ | 33.00$^{c}$ | 9.67$^{bc}$ | 13.33$^{ab}$ | 46.00$^{c}$ |
| Mycorrhizae 6 spores pot$^{-1}$ | Control | 38.00$^{abc}$ | 30.33$^{cd}$ | 13.00$^{b}$ | 9.67$^{bc}$ | 43.57$^{d}$ |
| | Cow manure | 36.00$^{abcde}$ | 38.00$^{b}$ | 12.00$^{b}$ | 13.33$^{ab}$ | 35.$^{23hi}$ |
| | Biochar | 34.00$^{efgh}$ | 20.00$^{ghi}$ | 13.00$^{b}$ | 11.67$^{abc}$ | 47.93$^{c}$ |
| | Clay-soil | 32.33$^{ghi}$ | 17.00$^{i}$ | 7.33$^{c}$ | 15.33$^{ab}$ | 26.03$^{k}$ |
| | Cow manure+Biochar | 35.00$^{abc}$ | 21.00$^{fg}$ | 14.00$^{b}$ | 18.33$^{ab}$ | 39.60$^{g}$ |
| | Cow manure+Clay-soil | 40.00$^{a}$ | 44.33$^{a}$ | 22.33$^{a}$ | 26.33$^{a}$ | 58.80$^{a}$ |
| | Biochar+Clay-soil | 33.00$^{fghi}$ | 20.33$^{fgh}$ | 3.67$^{c}$ | 3.67$^{c}$ | 31.93$^{ij}$ |

Numbers followed by different letters showed results that had a noticeable effect according to TUKEY test ($\alpha = 0.05$)

time of hyphal change. Hyphal activity stops a few weeks later released by hyphae and mixes with soil until the fungus dies. Glomalin will increase the stability of the sandy soil aggregate (Syamsiyah *et al*., 2018). A combination of mycorrhizae and clay-soil was the best for soil aggregate stability because clay soil has high plasticity that binds soil particles to form sandy soil aggregates.

The Pearson correlation test value evidences this statement; that water content strongly correlates with aggregate stability ($p \leq 0.05$), increasing soil aggregate and increasing soil moisture (Figure 9a). Soil aggregation is also caused by the treatment of clay soil, which acts as a binder between particles, thereby facilitating aggregation of sandy soil.

Increasing soil porosity from 39.85% to 49.56% with adding mycorrhizae and biochar (M1A2) impacted on increasing soil water content. Evidenced by the Pearson correlation test value, the strong correlation between the increase in soil porosity and soil moisture ($p \leq 0.05$) (Figure 9b). Biochar is broadly stable in soil. It has potential to provide a direct and long-term modification to soil water holding capacity through macroporous nature. Abel *et al*., (2013) reported that water retention in Terra Preta was 18% higher than in soils where charcoal was low or absent. Biochar can replace pores between sand grains and block some of the original soil drainages, thereby reducing vertical infiltration and reducing permeability. The direct impact of adding biochar is soil texture, but this effect must be short-lived as physically biochar appears to divide rapidly in soil to particles of silt size or less. In the longer term, biochar's effect suggests that available moisture will be positive in sandy soils ordinarily dominated by larger pores than present in biochar.

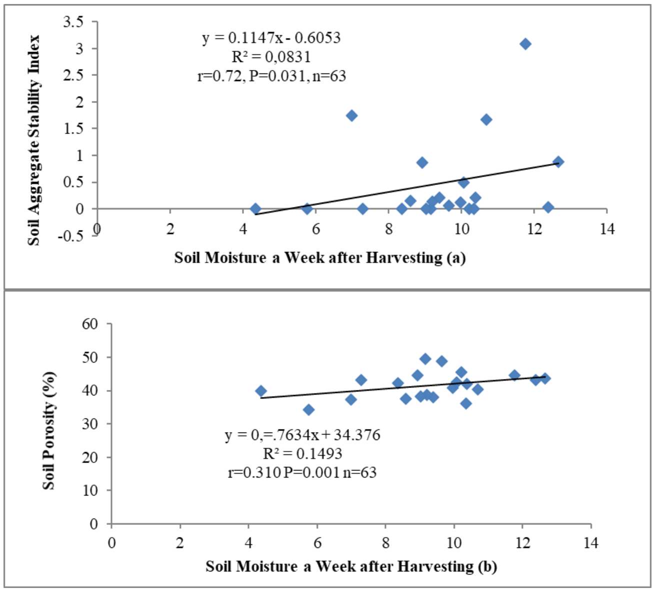


**Figure 9. Correlation between soil moisture a week after harvest and soil aggregate stability index (a) and the correlation between soil moisture a week after harvest and soil porosity (b)**

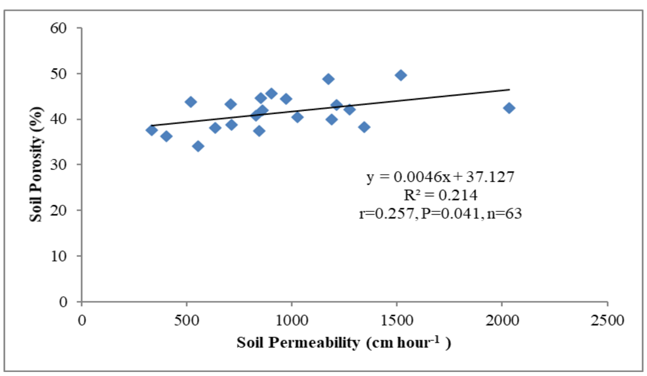


**Figure 10. Correlation between soil permeability and soil porosity**

The increase in soil porosity (49.56%) affects the decrease in soil permeability, evidenced by the negative correlation between soil porosity and soil permeability ($p \leq 0.05$). High soil porosity can hold water more to reduce the permeability rate (Figure 10). Adding high biochar can form new drainage channels; a certain additional proportion of biochar is useful for slowing the infiltration rate in a vertical direction, but excessive addition increases vertical infiltration. Adding mycorrhizae, biochar, and clay soil in sandy soils can increase the soil water content so that plant water availability is fulfilled. Soil amendments can reduce water loss due to evaporation and infiltration. This combination was the best for increasing soil moisture, soil porosity, soil aggregate stability, and decreasing soil permeability.

## Correlation between plant height, plant weight, root weight, root volume and yield

Application of mycorrhizaee 6 spores pot-1 and cow manure-clay soil showed the highest on plant height, plant weight, root weight, root volume and yield. Adding of mycorrhizaee 6 spores pot-1 and cow manure-clay soil (M2A5) increased plant height 0.3 times; plant height 2.5 times; root weight 1.79 times; root volume 1.93 times and yield 0.4 times compared to control. Pearson's correlation test showed that plant height was positively correlated with plant height ($p \leq 0.01$) and yield ($p \leq 0.01$), which means that an increase in plant height will be followed by an increase in plant height and yield. Kamal, et al., (2020) reported that mycorrhizaee treatment could increase the height of red chilies (Capsicum annuum L.) in Andisols. According to Prasasti et al., (2013), adding mycorrhizaee in plants have better growth than a plant without mycorrhizaee treatment because mycorrhizaee can increase water and nutrient uptake so that the metabolic processes and photosynthesis of plant was getting better. This increase in metabolism was accompanied by an increase in plant growth and development, such as plant height, plant height and yield of chilies.

The Pearson correlation test showed that root weight was positively correlated with root volume ($p \leq 0.01$) and yield ($p \leq 0.01$), indicated that an increase in plant root weight would be followed by an increase in root volume and yield. Jaenudin and Sugesa (2019) reported that mycorrhizaee and cow manure can increase root volume in flower cabbage plants. According to Firdaus et al., (2013), increasing the number of roots would increase root volume and fresh root weight. Mycorrhizaee treatment can increase root volume because mycorrhizaee in the roots can absorb more nutrients in the soil than roots without mycorrhizaee (Ginting et al., 2018).

Arbuscular mycorrhizael fungi had thinner and longer hyphae than root hairs so that they can reach soil that cannot be reached by plant root hairs and can absorb nutrients more efficiently (Osorio & Mitiku, 2013). Hu et al., (2009) reported that mycorrhizaee inoculation gave a higher response to plant biomass and yields of maize (Zea mays L.) than only fertilizer treatment on sandy soil

## Conclusions

Our finding shows that mycorrhizae and soil amendment application has a noticeable effect on physical characteristics of sandy soil. Mycorrhizae and the combination of biochar with clay soil (M1A6) can increase average soil moisture after harvesting (12.65%) 2.9 than the control. Mycorrhizae 6 spores $pot^{-1}$ and the combination of biochar-clay soil (M2A6) decreased the permeability rate (304.1 cm $hours^{-1}$) 3.9 more than the control. Mycorrhizae 3 spores $pot^{-1}$ and clay soil (M1A3) increased aggregate stability index, 3 times than control. Mycorrhizae 3 spores $pot^{-1}$ and biochar (M1A2) increased soil porosity (49.56%) 1.27 more than control (M0A0). Mycorrhizaee 6 spores pot-1 and the combination of cow manure-clay soil (M2A5) was the best for plant height, plant weight, root weight, root volume and yield of chili.

## Acknowledgements

Sebelas Maret University supported this research through PNBP Grant. Thanks to the Department of Soil Science, Faculty of Agriculture, Sebelas Maret University for helping this research and the laboratory facility.

## References

Abel, S., A. Peters, S. Trinks, H. Schonsky, M. Facklam and G. Wessolek. 2013. Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. *Geoderma* 202–203*:* 183–191.

Amézketa, E. 1999. Soil aggregate atability: A Review. *Journal of Sustainable Agriculture* 14(2–3): 83–151.

Astiko, W., I.R. Sastrahidayat, S. Djauhari and A. Muhibuddin. 2013. The role of indigenous mycorrhizae in combination with cattle manure in improving maize yield (Zea mays L) on sandy loam of northern lombok, eastern of Indonesia. *Journal of Tropical Soils* 18(1): 53–58.

Bai, Y., B. Pan, T.C. Charles and D.L. Smith. 2002. Co-inoculation dose and root zone temperature for plant growth-promoting rhizobacteria on soybean [Glycine max (L.) Merr] grown in soil-less media. *Soil Biology and Biochemistry* 34(12): 1953–1957.

Constantino, M., R. Gómez-Álvarez, J.D. Álvarez-Solís, V. Geissen, E. Huerta and E. Barba. 2008. Effect of inoculation with rhizobacteria and arbuscular mycorrhizael fungi on growth and yield of capsicum chinense jacquin. *Journal of Agriculture and Rural Development in the Tropics and Subtropics 109*(2): 169–180.

Dariah, A., Sutono and N.L. Nurida. 2010. Penggunaan pembenah tanah organik dan mineral untuk perbaikan kualitas tanah Typic Kanhapludults Tamanbogo, Lampung. *Jurnal Tanah Dan Iklim* 31: 1–9.

Firdaus, L. N., S. Wulandari and G.D. Mulyeni. 2013. Pertumbuhan akar tanaman karet pada tanah bekas tambang bauksit dengan aplikasi bahan organik. *Jurnal Pendidikan Sains dan Biologi* 10(1): 53-64.

Ginting, I. F., S. Yusnaini., Dermiyati and M.V. Rini. 2018. Pengaruh inokulasi fungi mikoriza arbuskular dan penambahan bahan organik pada tanah pasca penambangan galian C terhadap pertumbuhan dan serapan hara P tanaman jagung (*Zea mays* L.). *J. Agrotek Tropika* 6(2): 110-118.

Hu, J., X. Lin., J. Wang., J. Dai., X. Cui., R. Chen and J. Zhang. 2009. Arbuscular mycorrhizael fungus enhances crop yield and P-uptake of maize (Zea mays l.): A field case study on a sandy loam soil as affected by long term P-deficiency fertilization. *Soil Biology and Biochemistry* 41(12): 2460-2465.

Jaenudin, A. and N. Sugesa. 2019. Pengaruh pupuk kandang dan cendawan mikoriza arbuskular terhadap pertumbuhan, serapan N dan hasil tanaman kubis bunga (*Brassica oleracea* var. Botrytis L.). *Agroswagati* 6(1): 667-677.

Johannes, L. 2007. Bio-Energy in the Black. *Frontiers in Ecology and the Environment* 5(9): 381–387.

Kamal, M., Syamsuddin and Syafruddin. 2020. Pengaruh jenis mikoriza terhadap pertumbuhan dan hasil beberapa varietas cabai merah (Capsicum annuum L.) pada tanah Andisol Lembah Seulawah Aceh Besar. *Jurnal Ilmiah Mahasiswa* 5(2): 61-70.

Kammann, C., S. Ratering, C. Eckhard and C. Müller. 2012. Biochar and hydrochar effects on greenhouse gas (carbon dioxide, nitrous oxide, and methane) fluxes from soils. *Journal of Environmental Quality* 41(4): 1052-1066.

Liu, Z., B. Dugan, C.A. Masiello and H.M. Gonnermann. 2017. Biochar particle size, shape, and porosity act together to influence soil water properties. *PLoS ONE 12*(6): 1–19.

Osorio, N.W. and M. Habte. 2013. Synergistic effects of a phosphate-solubilizing fungus and an arbuscular mycorrhizael fungus on Leucaena seedlings in an Oxisol fertilized with rock phosphate. *Botany* 91: 274-281.

Mastur, S., D. Suswati and M. Hatta. 2017. The effect of ameliorants on improvement of soil fertility in post gold mining land at West Kalimantan. *Journal of Degraded and Mining Lands Management 04*(04): 873–880.

Park, J., Y. Lee, C. Ryu and Y.K. Park. 2014. Slow pyrolysis of rice straw: Analysis of products properties, carbon, and energy yields. *Bioresource Technology 155*: 63–70.

Prasasti, O.H., K.I. Purwan and S. Nurhatika. 2013. Pengaruh mikoriza Glomus fasciculatum terhadap pertumbuhan vegetatif tanaman kacang tanah yang terinfeksi patogen Sclerotium rolfsii. *Jurnal Sains dan*

*Seni POMITS* 2(2):74-78.

Prasetyo, R. 2014. Pemanfaatan berbagai sumber pupuk kandang sebagai sumber n dalam budidaya cabai merah (capsicum annum l.) di tanah berpasir. *Planta Tropika: Journal of Agro Science* 2(2): 125-132.

Pu, S., G. Li, G. Tang, Y. Zhang, W. Xu, P. Li, G. Feng and F. Ding. 2019. Effects of biochar on water movement characteristics in sandy soil under drip irrigation. *Journal of Arid Land 11*(5): 740–753.

Rahayu, R., J. Syamsiyah, V.R. Cahyani and S.K. Fauziah. 2019. The effects of biochar and compost on different cultivars of shallots (*allium ascalonicum L.*) growth and nutrient uptake in sandy soil under saline water. *SAINS TANAH - Journal of Soil Science and Agroclimatology* 16(2): 216.

Rahayu, J. Syamsiyah and L.N. Sa'diyah. 2020. Aggregate stability of Alfisols root zone upon turfgrass treatment. *Sains Tanah* 17(1): 50–56.

Riptanti, E.W., M. Masyhuri, I. Irham, A. Suryantini and M. Mujiyo. 2018. The development of leading food commodities based on local wisdom in food-insecure area in East Nusa Tenggara province, Indonesia. *Applied Ecology and Environmental Research 16*(6): 7867–7882.

Rusli, R., Y. Ferry, B. Hafif and E. Wardiana. 2016. The effectiveness of ameliorants, fertilizer, and mycorrhizae for rubber growth at post tin mining land. *Jurnal Tanaman Industri Dan Penyegar* 3(3): 175–184.

Santana, N.A., P.A.A. Ferreira, C.P. Tarouco, I.S. Schardong, Z.I. Antoniolli, F.T. Nicoloso and R.J.S. Jacques. 2019. Earthworms and mycorrhizaetion increase copper phytoextraction by *Canavalia ensiformis* in sandy soil. *Ecotoxicology and Environmental Safety* 182(6): 109383.

Sika, M.P. 2012. Effect of biochar on chemistry , nutrient uptake and fertilizer mobility in sandy soil. Thesis. Stellenbosch University, South Africa.

Sohi, S.P., E. Krull, E. Lopez-Capel and R. Bol. 2010. A review of biochar and its use and function in soil. *Advances in Agronomy* 105(1): 47–82.

Solaiman, M.Z. and H. Hirata. 1995. Effects of indigenous arbuscular mycorrhizael fungi in paddy fields on rice growth and N, P, K nutrition under different water regimes. *Soil Science and Plant Nutrition* 41(3): 505–514.

Syamsiyah, J., B.H. Sunarminto, E. Hanudin and J. Widada. 2014. Pengaruh inokulasi jamur mikoriza arbuskula terhadap glomalin, pertumbuhan dan hasil padi. *SAINS TANAH - Journal of Soil Science and Agroclimatology* 11(1): 39–46.

Syamsiyah, J., A. Herawati and Mujiyo. 2018. The potential of arbuscular mycorrhizael fungi application on aggregrate stability in alfisol soil. *IOP Conference Series: Earth and Environmental Science* 142(1): 012045.

Taek, R. 2016. Pengaruh takaran arang sekam dan guano terhadap pertumbuhan dan hasil kacang hijau (*Vigna radiata L.*). *Savana Cendana* 1(04): 121–124.

Tang, J., W. Zhu, R. Kookana and A. Katayama. 2013. Characteristics of biochar and its application in remediation of contaminated soil. *Journal of Bioscience and Bioengineering* 116(6): 653–659.

Wang, D., S.J. Fonte, S.J. Parikh, J. Six and K.M. Scow. 2017. Biochar additions can enhance soil structure and the physical stabilization of C in aggregates. *Geoderma* 303(5): 110–117.

Widiyawati, I., T. Harjoso and T.T. Taufik. 2016. Aplikasi pupuk organik terhadap hasil kacang hijau (Vigna radiate L.) di ultisol. *Kultivasi* 15(3): 159–163.

Xu, P., C.X. Sun, X.Z. Ye, W.D. Xiao, Q. Zhang and Q. Wang. 2016. The effect of biochar and crop straws on heavy metal bioavailability and plant accumulation in a Cd and Pb polluted soil. *Ecotoxicology and Environmental Safety* 132: 94–100.

Zhang, M., G. Cheng, H. Feng, B. Sun, Y. Zhao, H. Chen and A. Zhang. 2017. Effects of straw and biochar amendments on aggregate stability, soil organic carbon, and enzyme activities in the Loess Plateau, China. *Environmental Science and Pollution Research* 24(11) 10108–10120.

Zhang, Y., H. Li, A. Abdelhady and J. Yang. 2020. Comparative laboratory measurement of pervious concrete permeability using constant-head and falling-head permeameter methods. *Construction and Building Materials 263*: 120614.

Zhou, H., C. Chen, D. Wang, E. Arthur, Z. Zhang, Z. Guo and S.J. Mooney. 2020. Effect of long-term organic amendments on the full-range soil water retention characteristics of a Vertisol. *Soil and Tillage Research* 202(2): 104663.