Effect of arbuscular mycorrhiza and organic matter type toward growth and yield of sorghum on Oxisol Tuntang

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Abstract. Utilization Oxisol as plant growth media for sorghum is still limited. The main problems of the cultivation in Oxisol are low pH, high soluble form of Al, Mn, Fe, low organic matter (OM) and lack of nutrients especially P. The purpose of the present research was to examine the effect of arbuscular mycorrhiza (AM) and OM type toward the growth and yield of sorghum on Oxisol Tuntang. The pot experiment was conducted in greenhouse using factorial completely randomized design with two factors of AM inoculation and OM type with three replications. The first factor was inoculation of AM: without and with AM inoculation. The second factor was OM type: without OM, elephant grass compost, cow dung compost, worm castings and goat manure. The inoculation of AM in interaction with OM significantly increased AM colonization, spore density, leaf number, dry weight, water uptake, P concentration, P uptake and grain mass. Interaction of AM with worm castings and interaction of AM with goat manure indicated the same higher effect on sorghum growth and yield, compared with the interaction of AM with elephant grass compost and interaction of AM with cow dung compost. The control treatment showed the lowest plant performance.

1. Introduction
Sorghum is one of important cereal crops in the world which placed fifth after rice, wheat, maize and barley [1]. Sorghum is also the second important crop in semi-arid tropics because of its tolerant nature for dry soil condition and low water requirement compared to other cereal crops such as maize and wheat [2]. The nutrient composition of sorghum was similar to rice and wheat, such as: 72.09% of carbohydrate (79.34% rice, wheat 76.31%), and 10.62% of protein (6.61% rice, wheat 10.33%) which make it very potential as substitute food source [3].

Most lands in the tropics have low fertility level and have limitations in their intensive use, especially Oxisols dry land (covering 22.5% of the total land area in the tropics) [4]. Oxisols are soil type with adequate physical properties for plant growth but has low chemical fertility such as high acidity and an imbalance nutrient content. Oxisols are easily eroded which brings P and K nutrient are easily bounded by Al, Mn and Fe and make these nutrients to be unavailable for plants that causing P and K deficiency. Al, Mn and Fe will dissolve easily in acidic conditions and they are toxic to plants [5].

Sorghum cultivation on Oxisol is limited by many limitation factors resulting in low sorghum productivity. The strategy to overcome the problems is by inoculating arbuscular mycorrhiza (AM) and applying organic matter (OM) to the soil. AM has mutualistic symbiosis with plant roots by its
role in nutrients uptake especially P and also water uptake [8-10], while plants provide organic C for AM for its growth and development [11].

OM is able to support soil chemical fertility, stabilizing soil pH due to its buffer properties [6]. OM is also proven to improve the quality of soil biology by providing soil organic C [7]. The present study aimed to examine the effect of AM and OM type toward the growth and yield of sorghum on Oxisol Tuntang.

2. Materials and Methods

2.1 Soil preparation
Oxisol Soil from Tuntang, Semarang Regency, by geographical location of 7°21’08” S - 110°28’43” E was used as a planting medium. Soil samples were taken randomly from non-cultivated land then air-dried and sieved using a 2 mm diameter soil filter and put into a 15×25 polybag.

2.2 OM preparation
OM used was elephant grass compost, cow dung compost, worm castings and goat manure. Each OM was analyzed for its chemical characteristics before application.

2.3 AM inoculum source
The source of mycorrhizal inoculum used was AM culture with zeolite media which was dominated by the genus *Glomus* sp. with spore density of 182 – 238 100 g⁻¹ media. AM density analysis was carried out by wet filtration and centrifugation method which continued by AM genus analysis using Melzer staining.

2.4 Pot experiment
This study used a completely randomized design with a factorial pattern. The first factor was AM (M) with two levels: without AM (M0) and with AM (M1) inoculation. The second factor was OM types (P) with 5 treatments: without OM input (P0), 248.16 g elephant grass compost (P1), 195.17 g cow dung compost (P2), 223.09 g worm castings (P3) and 235.43 g goat manure (P4). From two factors above, 10 combinations of treatments were obtained then repeated three times to obtain 30 experimental units. Calculation of OM dosage was based on the requirement to achieve to the level of 2% of the total organic C content, by considering the total C content in soil and the total C in the each type of OM used in the present study.

2.5 OM incubation
OM was mixed with soil until it is homogeneous in a polybag. This medium was then moistened with tap water to about 70% of field capacity and incubated for 10 days before planting.

2.6 Planting and AM inoculation
Planting was done after 10 days of OM incubation by making a hole as deep as ± 3 cm filled with 2 seeds. The hole was covered with thin soil layer and then watered using a sprayer. After 7 days, thinning was done by leaving one plant per polybag. AM inoculation was done by making a hole as deep as ± 7 cm around and under the root of the plant and then added AM inoculum 25 g / pot culture (± 50 spores / pot culture). Soil moisture was managed around 70% field capacity during plant growth. Plants were harvested on 126 days after planting (DAP).

2.7 Variable observation
The observed variables were soil pH, AM infectivity (the percentage of root infection and spore density), AM effectiveness (plant height, shoot fresh and dry weight, root fresh and dry weight, flowering time, P concentration, P uptake) and the production of Sorghum grains (total grain weight and 100 grains weight).
3. Results and Discussion

3.1 Characteristics of Oxisol Tuntang and organic matters type

Oxisol Tuntang used as planting media in the present study based on the criteria of the assessment of soil analysis according to Balai Penelitian Tanah Indonesia (Indonesian of Soil Research Center, 2009) had slightly acidic pH, low total N, available P, available K and very low total organic C (Table 1).

The four kinds of OM used in this study had slightly alkaline pH (Table 1). The C/N ratio of all OM ranged from 15.11 – 16.03. According to Peraturan Menteri Pertanian Republik Indonesia (Regulation of the Minister of Agriculture of the Republic of Indonesia) No.70/Permentan/SR.140/10/2011, the minimal requirement for quality standard of C/N ratio for OM is around 15-25.

Table 1. Soil characteristics and organic matters analysis

| Parameter          | Soil Different type of organic matters |
|--------------------|----------------------------------------|
|                    | EGC          | CDC          | WC           | GM           |
| pH H2O             | 5.8          | 7.5          | 7.8          | 7.9          | 7.7          |
| Total N (%)        | 0.12         | 1.26         | 1.51         | 1.33         | 1.31         |
| Total P (%)        | -            | 1.48         | 1.61         | 1.81         | 1.53         |
| Available P (ppm) | 1.82         | -            | -            | -            | -            |
| Total K (%)        | -            | 1.47         | 1.55         | 1.78         | 1.79         |
| Available K (me%)  | 0.70         | -            | -            | -            | -            |
| Organic C (%)      | 0.65         | 19.04        | 24.21        | 21.18        | 20.07        |
| Ratio C/N          | 5.42         | 15.11        | 16.03        | 15.92        | 15.32        |

EGC (elephant grass compost), CDC (cow dung compost), WC (worm castings), GM (goat manure)

3.2 Soil pH

Based on ANOVA results, it was found that the OM treatment had a very significant effect on soil pH, while AM and its interaction with OM had no significant effects. Figure 1 shows that the treatments of all OM had statistically the similar effect in increasing pH to the range of 6.43 - 6.51.

Figure 1. The effect of organic matters on soil pH. P0 (without OM), P1 (elephant grass compost), P2 (cow dung compost), P3 (worm castings), P4 (goat manure)

3.3 Mycorrhizal infectivity (percentage of root infection and spore density)

ANOVA results showed that the interaction of AM and OM had significant effect on root infection and spore density of AM. AM colonization in plant root and AM spores were found in all treatments with inoculation of AM and were not found in all treatment without AM (Figure 2).

The highest infection was obtained in the treatment of M1P3 (23.33%), followed by the treatment of M1P4 (20%), M1P1 (18.33%), M1P2 (15%) and the lowest M1P0 (11.67%). The highest spore density was indicated in the treatment of M1P3 (60.00 spores/100g soil), M1P1 (57.33 spores/100g soil) and M1P4 (56.33 spores/100g soil) followed by the treatments of M1P2 (50.67 spores/100g soil)
and M1P0 (49.33 spores/100g soil). According to Gryndler et al. [12] and Leigh et al. [13], AM mycelium activity is influenced by the decomposition of organic matter through compounds released during the decomposition process and also by the secondary metabolites of microorganisms involved in the decomposition of organic matter.

Correlation analysis showed that spore density was positively correlated (r=0.991**) with root infection by AM. The higher percentage of AM infection was followed by higher spores density. This is in accordance with the report by Douds and Schenck [14] and Hindumathi and Reddy [15] which stated that sporulation increased along with increasing AM infection or colonization in the root system.

**Root infection (%)**

| T       | PH (cm)    | LN     | SFW (g)  | SDW (g)  | RFW (g) | RDW (g) | FT (dap) |
|---------|------------|--------|----------|----------|---------|---------|----------|
| M0P0    | 215.9 ±5.18 | 14.7 ±0.58 a | 263.9 ±7.98 a | 94.1 ±3.28 a | 94.2 ±3.87 a | 35.8 ±1.83 a | 84.3 ±3.06 |
| M1P0    | 233.0 ±21.34 | 15.7 ±0.58 ab | 292.4 ±6.79 bc | 103.5 ±1.46 bc | 113.0 ±2.60 b | 42.9 ±0.88 b | 86.7 ±10.26 |
| M0P1    | 260.4 ±16.85 | 16.7 ±0.58 b | 302.4 ±10.17 cd | 109.3 ±2.34 c | 117.7 ±1.28 b | 44.6 ±0.54 bc | 84.0 ±1.73 |
| M1P1    | 255.4 ±2.90 | 18.7 ±0.58 ed | 316.7 ±5.17 e | 112.9 ±2.69 ed | 123.8 ±1.44 e | 47.0 ±1.01 c | 84.7 ±1.53 |
| M0P2    | 235.1 ±32.46 | 17.0 ±1.00 bc | 283.8 ±6.78 b | 101.1 ±1.45 bc | 131.1 ±3.97 d | 49.7 ±0.98 d | 80.0 ±5.00 |
| M1P2    | 223.0 ±18.21 | 19.3 ±0.58 d | 310.3 ±2.16 de | 110.6 ±1.75 c | 140.3 ±1.64 e | 53.2 ±0.60 e | 77.3 ±2.08 |
| M0P3    | 246.8 ±29.90 | 17.3 ±0.58 bc | 334.3 ±9.07 f | 119.1 ±2.17 d | 181.2 ±2.46 h | 68.7 ±0.75 h | 78.7 ±3.51 |
| M1P3    | 240.9 ±28.18 | 22.7 ±0.58 e | 345.5 ±5.51 f | 123.1 ±2.98 h | 198.8 ±2.80 i | 75.4 ±1.04 i | 78.0 ±1.73 |
| M0P4    | 257.1 ±24.46 | 17.3 ±2.52 bc | 336.6 ±2.51 f | 120.9 ±1.40 d | 164.7 ±2.65 f | 62.5 ±1.66 f | 81.7 ±3.51 |
| M1P4    | 246.3 ±5.03 | 21.3 ±0.58 a | 343.5 ±6.82 f | 122.4 ±2.01 d | 171.9 ±7.61 g | 65.2 ±2.94 g | 78.7 ±1.15 |

Numbers followed by the same letter show no significant difference in 5% DMRT. T (treatments), PH (plant height), LN (leaf numbers), SFW (shoot fresh weight), SDW (shoot dry weight), RFW (root fresh weight), RDW (root dry weight), FT (flowering time), M0 (without AM), M1 (with AM inoculation), P0 (without OM), P1 (elephant grass compost), P2 (cow dung compost), P3 (worm castings), P4 (goat manure)

As presented in Table 2, the lowest number of leaves obtained in the control treatment (14.7), while the highest number of leaves was obtained in the treatment of M1P3 (22.7) and M1P4 (21.3) that were 44.9 - 54.4% higher compared to control. The lowest shoot dry weight obtained in the control treatment (94.1 g), while the highest shoot dry weight obtained in the treatment of M1P3 (123.1 g), M1P4 (122.4 g), M0P4 (120.9 g) and M0P3 (119.1 g) that were 26.6 - 30.9% higher compared to the control. The lowest root dry weight obtained in control treatment (35.8 g), while the highest root dry weight was obtained in M1P3 (75.4 g) that was 110.9% higher compared to the control. The AM inoculation showed the highest shoot and root fresh weight than non-inoculation treatment, these results indicated the improvement of water uptake. The enhancement of water uptake was mediated by

3.4 Plant growth

ANOVA results showed that AM and OM interactions significantly affected the number of leaves, shoot fresh and dry weight, root fresh and dry weight but did not significantly affect the plant height and flowering time (Table 2).

**Figure 2.** The effect of arbuscular mycorrhiza and organic matter on root infection and spore density. M0 (without AM), M1 (with AM inoculation), P0 (without OM), P1 (elephant grass compost), P2 (cow dung compost), P3 (worm castings), P4 (goat manure)
the role of AM fungal hyphae [16]. The highest shoot and root fresh weight was indicated by MIP3 which explained that worm castings gave higher effect compared with the other OM types. This result was supported by Hameeda et al [17].

The treatment of AM inoculation showed higher sorghum growth responses than without AM inoculation (Table 2). Correlation analysis showed that AM infectivity was positively correlated with the number of leaves (r=0.671**), shoot fresh weight (r=0.390*), shoot dry weight (r=0.371*), root fresh weight (r=0.264) and root dry weight (r=0.263). These results were similar with other research results that showed the roles of mycorrhiza for increasing plant growth [18-19].

3.5 P concentration, P uptake and sorghum yield

ANOVA results showed that AM and OM treatment had significant effect on P content in plant tissue, P uptake, grain yield and weight of 100 sorghum grains (Table 3).

Table 3. Effect of arbuscular mycorrhiza and organic matter on plant P and grain yield.

| Treatment | P concentration (%) | P uptake (g pot⁻¹) | Grain yield (g/plant) | 100 grains weight (g/plant) |
|-----------|---------------------|--------------------|-----------------------|------------------------------|
| M0P0      | 0.0054 ±0.000062 a  | 0.701 ±0.0221 a    | 41.22 ±0.267 a        | 4.18 ±0.134 a                |
| M1P0      | 0.0059 ±0.000045 b  | 0.857 ±0.0095 b    | 41.55 ±0.213 a        | 4.19 ±0.059 a                |
| M0P1      | 0.0055 ±0.000089 a  | 0.853 ±0.0210 b    | 47.45 ±0.484 c        | 4.27 ±0.045 a                |
| M1P1      | 0.0071 ±0.000075 e  | 1.135 ±0.0112 e    | 67.08 ±0.063 g        | 4.28 ±0.012 a                |
| M0P2      | 0.0060 ±0.000045 b  | 0.910 ±0.0106 c    | 53.89 ±0.487 e        | 4.25 ±0.056 a                |
| M1P2      | 0.0065 ±0.000136 d  | 1.073 ±0.0218 d    | 64.57 ±0.579 f        | 4.32 ±0.100 ab               |
| M0P3      | 0.0059 ±0.000165 b  | 1.113 ±0.0216 de   | 44.56 ±0.2246 b       | 4.24 ±0.088 a                |
| M1P3      | 0.0076 ±0.000091 f  | 1.502 ±0.0130 f    | 70.64 ±0.599 h        | 4.43 ±0.067 bc               |
| M0P4      | 0.0063 ±0.000107 c  | 1.146 ±0.0263 e    | 51.63 ±0.260 d        | 4.25 ±0.044 a                |
| M1P4      | 0.0081 ±0.000327 g  | 1.514 ±0.0723 f    | 71.79 ±1.376 h        | 4.50 ±0.076 c                |

Numbers followed by the same letter show no significant difference in 5% DMRT, M0 (without AM), M1 (with AM inoculation), P0 (without OM), P1 (elephant grass compost), P2 (cow dung compost), P3 (worm castings), P4 (goat manure)

As shown in Table 3, the lowest P concentration was obtained in the control treatment (0.0054%), while the highest one was obtained in M1P4 (0.0081%) that was 50% higher compared to control. The lowest P uptake was obtained in the control treatment (0.701 g/plant), whereas the highest P uptake was obtained in M1P4 (1.514 g/plant) and M1P3 (1.502 g/plant) that were 114.3 - 115.9% higher compared to control.

The lowest grain yield was obtained in the control treatment (41.22 g), while the highest grain yield was obtained in the treatment of M1P4 (71.79 g) and M1P3 (70.64 g) which were 71.4 - 74.2% higher compared to control. The highest 100 grains weight obtained in M1P4 (4.50 g) which was 7.7% higher compared to control.

Table 3 shows that the use of AM gave higher P concentration, P uptake and grain yield than without AM. AM can accelerate the movement of P to the root by increasing P affinity, increasing phosphatase activity and increasing phytohormone production which has an impact on changes in root functions to increase nutrient uptake [20]. Correlation analysis showed that P concentration and P uptake were positively correlated with grain yield and 100 grains weight. Phosphorus is needed for plant growth in the whole life cycle including vegetative to generative phases. Phosphorus nutrient plays important role in storing and transferring energy (ADP and ATP) obtained from photosynthesis and carbohydrate metabolism for the process of growth, grain production and accelerates maturity [21].

4. Conclusion

Among the four types of OM that were applied in this study, the highest effect of OM on AM infectivity in plant root was worm castings, followed by goat manure, elephant grass compost and cow dung compost. Three types of organic matter namely worm castings, elephant grass compost and goat manure showed similar effect on AM spore density, while cow dung compost showed a lower effect.
The treatment of AM inoculation showed better sorghum growth than without AM inoculation, which indicated by the variables of the number of leaves, shoot dry weight and root dry weight. The treatments of worm castings and goat manure showed higher plant growth compared with cow dung and elephant grass compost. The AM and OM interaction showed higher results on shoot and root fresh weight which also meant higher plant water uptake. The highest P uptake in sorghum was shown by goat manure and worm castings treatment followed by elephant grass compost and cow dung compost. The treatments of goat manure and worm castings showed higher grain yield compared with elephant grass compost and then following by cow dung compost. The main findings of the present study indicated that the interactions of AM with worm castings and AM with goat manure resulted in higher effectiveness on sorghum growth. P uptake and grain yield compared with the interactions of AM with elephant grass compost and AM with cow dung compost.

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