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Application of Humic Acid and Arbuscular Mycorrhizal Fungi to Increase Growth and Yields of Soybean in Ultisol

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ABSTRACT

Soybean is one of the most popular food crops for the community, but the needs for soybeans have not been fulfilled by soybean production. To meet the needs of soybeans, it is necessary to intensify agricultural land in Ultisol. This study aims to obtain the optimum concentration of humic acid and dosage of the Arbuscular Mycorrhizal Fungi (AMF) to increase soybean plants' production in Ultisols. This research was conducted from January to April 2020 in Beringin Raya Village, Muara Bangkahulu District, Bengkulu City, at an altitude of 10 m above sea level. The research design used a Randomized Complete Block Design (RCBD) two factors with three replications, arranged factorially in experimental units. The first factor is the concentration of humic acid, consisting of 4 levels: 0, 15, 30, and 45 mL L^{-1}. The second factor is the dose of AMF, consisted of 3 levels, namely: 0, 2.5, and 5 g $plant^{-1.}$ The results showed that the maximum soybean growth and yield in Ultisols were obtained from the humic acid concentration at 45 mL L^{-1} at the dose of AMF at 2.5 g $plant^{-1}$. The resulting production potential is 1.99 tons ha^{-1}. The administration of humic acid or AMF independently at this research stage had not yet given a maximum response to the growth and yield of soybean in Ultisol.

Keywords: soybean, Ultisol, humic acid, Arbuscular Mycorrhizal Fungi

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is one of the most popular food crops globally, especially in Indonesia. Soybeans are used as staple food preparations, such as tempeh, tofu, taco, soy milk, and other food industry products. The advantage of soy is that it has a protein content of 40%. For every 100g of soybean seeds, there are also 21 g of carbohydrates, 7 g of fiber, and 2.76 g of magnesium (Winarsi, 2010).

The need for soybeans in Indonesia in 2015 reached more than 3 million tons, while soybean production in 2013-2015 was an average of 899,390 tons (Badan Pusat Statistik, 2016). Efforts to cover the soybean shortage have forced the country to import soybean from abroad. Based on data from the Central Statistics Agency (Badan Pusat Statistik, 2019), soybean imports in 2016-2018 have increased, the peak is as much as 2.58 million tons. Low domestic soybean production, one of the impacts of the lack of fertile land for soybean cultivation, is due to converting agricultural land to residential areas. One of the potential land for agriculture in Indonesia is marginal land from the Ultisols.

Ultisol soil is land with advanced leaching rates or acid forest soil with low fertility (Hakim, 2019). The land area of Ultisol is 107.36 million hectares or 74.31% of the 188.03 million hectares of agricultural land in Indonesia. Available in parts of the island of Kalimantan, Sumatra, and Papua (Pertanian, 2018) The main constraints in utilizing Ultisol soil are the high acidity and aluminum saturation (Al), low nutrient content, and sensitivity to erosion. The high solubility of Al and iron (Fe) absorbs phosphorus (P), so the availability of P for plants is low (Barchia, 2008). One of the improvements in Ultisol soil properties is the provision of organic materials such as mycorrhizae.

Mycorrhiza is a term that describes the symbiotic relationship between plant roots and fungi. The structure of AMF hyphae in plant roots can increase nutrient and water exchange between plants and hosts. It has excellent potential to increase nutrient uptake and translocation, especially P elements to plants (Utama & Yahya, 2003). Research by Wardhani *et al.* (2019) found that mycorrhizal application as much as 7.5 g plant^{-1} had no significant effect on P uptake and growth response of soybean plants but was able to increase available P in Ultisol soil. Another moment, the application of AMF was able to increase soybean production on Ultisols from AMF inoculant treatment of ± 1,000 spores with a combination of cow manure as much as 20 tons ha^{-1}. However, cow manure has not significantly affected the response to growth and yield of soybean with AMF (Malik *et al*., 2017). So, a new solution for AMF companion in Ultisols is needed, one of which is by giving humic acid.

Humic acid is a macromolecular organic acid with acidic properties determined by the –COOH and –OH phenolic groups; these groups are the most reactive in binding metal cations (Stevenson, 1994). Carboxylate groups (-COOH) will dissociate at soil pH. H + ions are firmly bound to organic soil colloids in acidic conditions, so they are not easily replaced by other cations (Handayanto *et al*., 2017). Humic acid binds to the Fe^{3+} and Al^{3+} cations (abundant in Ultisol soil). A trivalent cation is deposited, and the sediment dissolves again, along with an increase in pH above 7 (Santosa, 2014). Research 1,200 ppm humic acid treatment was the best treatment in increasing P uptake and growth of soybean plants (Wahyuningsih *et al*., 2016). Besides, soils with residual effects of humic acid at a rate of 600 ppm can also suppress soil Fe solubility to near non-toxic levels, with the lowest soil Fe solubility range between 36.08–68.56 ppm (Ruhaimah *et al*., 2009).

This study aims to obtain the optimum interaction of humic acid concentration at several AMF doses on the growth and yield of soybean in Ultisols. and determine the optimum concentration of humic acid and the optimum amount of AMF on the growth and yield of soybean in Ultisols

MATERIAL AND METHOD

The research was carried out from January to April 2020 in community agricultural gardens, Beringin Raya Village, Muara Bangkahulu District, Bengkulu, at 10 m above sea level. The research design used a Randomized Complete Block Design (RCBD) two factors with three replications, arranged factorially in experimental units. The first factor was the concentration of humic acid, consisting of 4 levels: 0, 15, 30, and 45 mL L^{-1}. The second factor was the dose of AMF, which consisted of 3 levels, namely: 0, 2.5, and 5 g plant^{-1}. The FMA inoculant in this study was obtained from the Laboratory of Soil Biology, Faculty of Agriculture, University of Bengkulu. The humic acid used was obtained from commercial liquid humic acid.

Soil analysis was carried out before land processing to analyze C-organic, pH, total N content, total P, total K, soil CEC and Al-dd (Al Ghifari *et al*., 2014). Soil management is in the form of cleaning the soil from weeds manually, processed with hoes. Map the experiment measuring 1.5 m x 2 m with the distance between the plots is 50 cm, and the distance between replicates is 1 m.

Basic fertilization is carried out a week before planting: organic fertilizer (cow manure) 10 tons ha^{-1}, followed by urea 25 kg ha^{-1}, KCl 50 kg ha^{-1}, and SP36 50 kg ha^{-1} at planting. The planting hole is made by cutting 3 cm - 5 cm deep. Soybean seeds are planted two seeds in each planting hole, with a spacing of 20 cm x 30 cm. Humic acid and AMF applications were carried out during planting.

Harvesting is done two times. Vegetative harvesting was carried out at 30 days after planting, with 3 sample plants per plot to take intact stems and soil around the rhizosphere. Generative harvest at 95 days after planting as many as 5 sample plants, when 95% of the soybean pods are brownish yellow, the leaves begin to fall, and the stems begin to dry out according to the variety description (Balai Penelitian Tanah, 2009). Generative harvesting is carried out in the morning to evening.

The observed growth and yield variables included: soil pH, percentage of root colonization, number and weight of nodules, plant height, number of leaves, number of productive nodes, number of pods, number of pithy pods, number and weight of seeds per plant, the weight of 100 seeds, dry stover weight, and P-tissue content. The data obtained were analyzed by analysis of variance (ANOVA) with a 5% significance level of the Orthogonal Polynomial test (OP) to compare the effect between treatments (Gomez & Gomez, 1983).

RESULT AND DISCUSSION

The results of the analysis of variance showed that the interaction between humic acid and AMF gave different responses significantly to soil pH, nodule weight, plant height, number of leaves, tissue P content, and seed weight per plant. The application of humic acid independently was significantly different from soil pH, the number of nodules, and dry stover weight. Meanwhile, AMF inoculation was significantly different from soil pH, root colonization percentage, number of seeds per plant, seed weight per plant, and dry stover weight. The variable number of productive books, number of pods, number of pithy pods, and weight of 100 seeds did not show a significantly different response from all treatments (Table 1).

The analysis results of the interaction between humic acid and AMF had a significant effect on soil

Table 1. Summary of Variance Analysis

No	Variables	Treatments (F-count)			Coefficient of variance (%)
		Interaction	Humic Acid	AMF	
1	Soil pH	10,98*	12,35*	26,71*	4,17
2	Root colonization	1,82ns	1,20ns	19,45*	37,37
3	Number of root nodules	1,93ns	6,28*	3,40ns	18,46
4	Weight of root nodules	2,76*	0,70ns	1,84ns	4,07
5	Plant height (cm)	3,04*	2,33ns	2,50ns	4,46
6	Number of leaves	3,78*	1,40ns	0,98ns	13,78
7	Number of productive books	1,08ns	1,76ns	0,58ns	8,65
8	Number of pods	0,91ns	0,83ns	0,59ns	28,89
9	Number of pithy pods	1,37ns	0,60ns	0,99ns	27,48
10	Number of seeds/plant^{-1}	2,45ns	0,25ns	4,08*	26,04
11	Weight of seeds/plant^{-1}	2,77*	0,43ns	4,03*	32,24
12	Weight of 100 seeds	1,16ns	0,01ns	0,75ns	7,13
13	Dry stover weight	0,79ns	7,96*	6,03*	24,61
14	Number of P-tissues content	4,86*	2,93ns	0,75ns	20,77

Note: ns= does not differ significantly, *= different significantly at the F-table level at 5%.

pH, nodule weight, plant height, number of leaves, P-tissue content, and seed weight per plant. The results of the further orthogonal polynomial test for those variables showed in Figures 1 to 6.

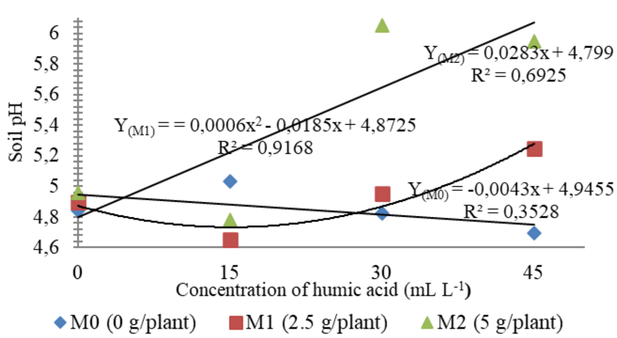

Figure 1. Relationship of humic acid concentration and soil pH at several AMF doses

The relationship between humic acid concentration and soil pH at the AMF dose of 5 g plant^{-1} (M_2) is a linear pattern with the equation Y (M_2) = 0.0283x + 4.799. Soil pH can increase by 0.0283, along with the increase in the concentration of humic acid at the AMF dose of 5 g plant^{-1}. The maximum potential pH that can be achieved is 6.07. The degree of determination (R^2) is 0.6925, meaning that 69.25% of the soil pH variability can be determined by the Y equation (M_2). On the other hand, the relationship of humic acid concentration at the AMF dose of 2.5 g plant (M_1) to soil pH formed a parabolic quadratic pattern. The equation formed is Y(M_1) = $0.0006x^2$-0.0185x + 4.8725 with R^2 = 0.9168. This indicates that giving the optimum concentration of humic acid 15.41 mL L^{-1} at an AMF dose of 2.5 g/plant will result in minimal soil pH. It is different when giving humic acid without AMF inoculation; it forms a negative linear pattern, with the equation Y (M_0) = 0.0043x - 4.9455. Giving humic acid independently when the concentration is increased will decrease the soil pH by 0.0043. However, the value of R^2 Y (M_0) is only 0.3528, meaning that the variability of soil pH can only be explained by 35.28% of the Y (M_0) equation, or in other words, 64.72% is influenced by factors outside the treatment (Figure 1).

In general, administration of humic acid with a concentration of 45 mL L^{-1} in AMF inoculation 5 g plant^{-1} has the potential to reach a maximum soil pH of 6.07; or in other words, it has succeeded in increasing the soil pH by 31.1% from the initial soil pH, it was 4.36. Compared with the research of Khairuna *et al.* (2015) AMF inoculation and compost gave the highest soil pH value of 5.76. The comparison of these results indicated that the interaction between AMF and humic acid was more effective in improving Ultisols' chemical properties.

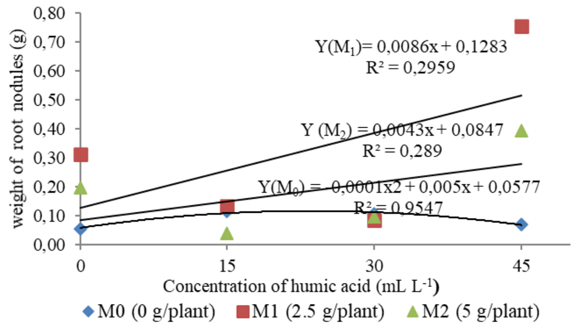

Figure 2. Relationship of humic acid and weight of root nodules at several AMF doses

Humic acid and AMF inoculation have the same function in improving soil properties: decomposing ions bound by Fe or Al in Ultisol soil. The increase in soil pH occurs due to the increase in OH- ions in the soil solution. Humic acid is known to contain –COOH (carboxyl) and –OH (phenolic), which are a source of negative charges (Stevenson, 1994). Besides, biological fertilizers can increase soil pH because it releases organic acids in the soil (Bertham, 2002). AMF in this study as a biological fertilizer. The role of AMF, in particular, lies in phosphorus uptake. Changes in pH in the rhizosphere impacted an important role in phosphorus availability (Purwati *et al*., 2019). Thus, the interaction of humic acid and AMF to improve soil properties is realized through the working mechanisms of humic acid and AMF, which support one another. Suppose AMF, through its enzymatic process, can decompose Al and Fe (Khairuna *et al*., 2015), humic acid will bind to the Al and Fe cations by donating negative ion groups, thereby increasing soil pH.

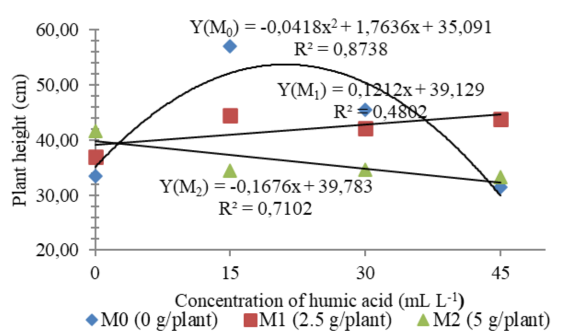

Figure 3. Relationship of humic acid concentration and plant height at several AMF doses

Changes in soil pH value indirectly affect plant growth components, one of which is the weight of root nodules the relationship between nodule weight and humic acid concentration at several AMF doses presented in Figure 2. The correlation pattern of humic acid concentration at the AMF dose of 5 g plant^{-1} (M_2) to the nodules' weight formed a linear pattern, with the equation Y (M_2) = 0.0043x + 0.0847. That indicates that the increase in humic acid concentration at the AMF dose of 5 g plant^{-1} will be accompanied by an increase in root nodule weight of 0.0043 g. The degree of determination (R^2) = 0.289, meaning that only 28.9% of the nodule weight variability can be explained by the Y (M_2) equation. The weight of nodules when given humic acid at an AMF dose of 2.5 g plant^{-1} (M_1) forms the equation Y (M_1) = 0.0086x + 0.1283, meaning that any increase in the concentration of humic acid at an AMF dose of 2.5 g plant^{-1} will be accompanied by an increase in root nodules weight of 0.0086 g. The maximum nodule weight achieved from 45 mL L^{-1} of humic acid with 2.5 g plant^{-1} AMF is 0.51 g. The value of determination, R^2, is 0.2959, indicating that the Y (M_1) equation can only explain 29.59% of the variability of nodule weight (Figure 2).

On the other hand, giving humic acid without AMF inoculation formed a quadratic pattern of nodule weight, with the equation Y (M_0) = $0.0001x^2 + 0.005x + 0.0577$ and R^2 = 0.9547. Given the optimum concentration of humic acid, 25 mL L^{-1}, the maximum nodule weight will be 0.12 g. However, giving humic acid above the optimum concentration will reduce nodules' weight (Figure 2). That because humic acid can inhibit urease activity (protein in bacteria) that can reduce nitrogen released through evaporation so that nitrogen availability in the soil increases.

The interaction of humic acid and AMF, apart from being significantly different in soil pH and nodule weight, also significantly different at plant height. Further tests on plant height are presented in Figure 3. The relationship between humic acid concentration and plant height, when inoculated with AMF 2.5 g plant^{-1} (M_1), formed a positive linear pattern, Y (M_1) = 0.1212x + 39.129 with the degree of determination of (R^2) = 0.4802. That indicates that each addition of humic acid concentration at the AMF dose of 2.5 g plant^{-1} will increase the plant height by 0.1212 cm. On the other hand, the relationship between plant height and humic acid concentration when inoculated with AMF 5 g plant^{-1} formed a negative linear pattern, with the equation Y (M_2) = -0.1676x + 39.783 and R^2 = 0.7102. Each addition of humic acid concentration at the AMF dose of 5 g plant^{-1} will inhibit plant height growth by 0.1676 cm. Different things were obtained when given humic acid without inoculating AMF (M_0), forming a quadratic relationship pattern with equation Y (M_0) = $-0.0418x^2 + 1.7636x + 35.091$. Giving humic acid independently at an optimal concentration of 21.09 mL L^{-1} will get a maximum plant height of 53.69 cm. However, offering humic acid above the optimal concentration will inhibit plant height growth by 0.0418 cm. The value of R^2 = 0.8738, meaning that 87.38% of plant height variability can be represented by the Y (M_0) equation (Figure 3).

Soybean growth is influenced by variety, environment, and nutrient population. Based on the variety's description, the actual plant height can reach 64-68 cm, with a definite type of growth. The research results from presenting humic acid and AMF inoculation at various levels tended to form low-growing plants from the actual plant posture. This is thought to be due to a lack of nutrient intake during the plant's vegetative phase. Soybean plants absorb significant amounts of N, P, K, Ca, Mg, S, and Cl from the soil, but soybeans are generally less responsive to direct fertilization (Sumarmono & Manshuri, 2013).

Growth indicators other than plant height can also be seen in the number of leaves—the relationship between the number of leaves and humic acid concentration at several AMF doses presented in Figure 4. Leaves are an important indicator of early soybean plant growth. Leaves as a place for photosynthesis to occur; in other words, the more leaves, the more energy can be produced. The number of leaves is influenced by the variety and environment as well as the availability of nutrients. The highest number of leaves from this study was obtained from the optimum concentration of humic acid at 21.09 mL L^{-1} independently, which was 13.43 leaves (Figure 4). Compared with Sumarmi & Tryono's research (Sumarmi & Triyono, 2018) stated in the same variety as this study, when normal conditions can produce 17 leaves. That indicates that neither humic acid nor AMF has provided an optimal response to the number of leaves (Figure 3).

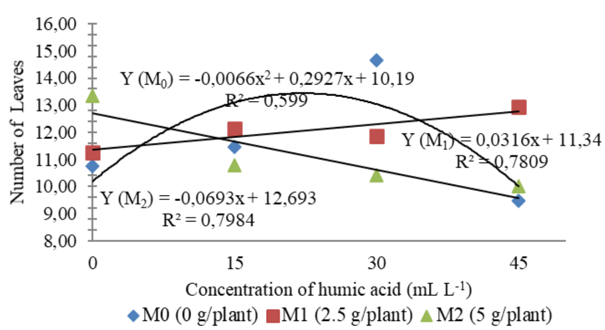

Figure 4. Relationship of humic acid concentration and number of leaves at several AMF doses

The interaction of humic acid and AMF inoculation also significantly affected the P-tissue content. The relationship between P-tissues content and humic acid concentration at several AMF doses presented in Figure 5. Giving humic acid with a concentration of 45 mL L^{-1} at an AMF dose of 5 g $plant^{-1}$ was able to provide a maximum P-tissue content of 1.89% (Figure 5). That is presumably because the addition of humic acid can release the P bonds bound to the Ultisols soil into cations that can be absorbed by plant roots characterized by soil pH that is close to normal 6.07 (Figure 1). In line with Bertham's research (Bertham, 2002), increasing the pH of acidic soil will cause a decrease in the solubility of Al ions so that they can be exchanged because organic acid scan classify metal ions. Consequently, inorganic phosphorus ions will be released into the soil, which will then be absorbed by plants. This is also confirmed by Nurhayati (Nurhayati, 2012), which states that the main function of hyphae in AMF is to absorb water from the soil, P that accumulates in external hyphae will immediately be converted into polyphosphate compounds in the presence of the enzyme phosphatase. Thus, the interaction of 45 mL L^{-1} humic acid concentration at an AMF dose of 5 g $plant^{-1}$ positively affected the P levels of plant tissue.

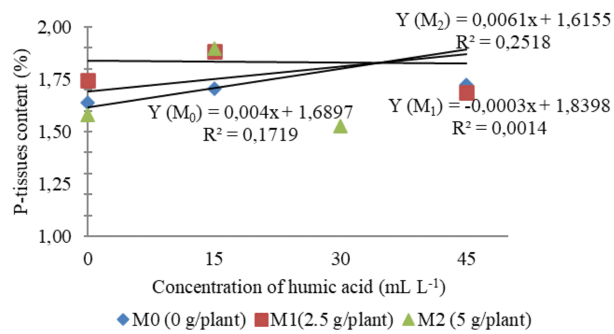

Figure 5. Relationship of humic acid concentr tion and P-tissues content at several AMF doses

Further tests of seed weight per plant from humic acid concentration at several AMF doses are presented in Figure 6. The maximum potential seed weight per plant from the application of humic acid 45 mL L^{-1} to the AMF 2.5 g $plant^{-1}$ inoculation was 13.31 g $plant^{-1}$ or equivalent to 1.99 tons ha^{-1} (Figure 6). Compared with the soybean varieties used, it has a yield potential of 2.03-2.25 tons ha^{-1}. The interaction between humic acid and AMF is still 1.97% less to achieve the real yield potential. The weight of seeds by the interaction between the humic acid concentration of 45 mL L^{-1} with an AMF dose of 2.5 g $plant^{-1}$ has a positive linear relationship (Figure 6). it means that the seed weight per plant has the potential to increase if the humic acid concentration increases at an AMF inoculation of 2.5 g $plant^{-1}$ on Ultisol soil.

Seed weight is closely related to the seed filling process that starts in the R5 phase. Based on the varieties used, this phase occurs after 40 days after planting. The seeds' size in the pods until 3 mm in one of the stem nodes (Adie & Krisnawati, 2013). Judging from the optimal work of humic acid on improving soil properties, on the first 45 days, the second 45 days performance of humic acid tends to decline (Wahyudi, 2007). On the other hand, during that time, the FMA inoculant will work optimally to absorb nutrients, especially P. This statement supposed by Malik *et al.* (2017) stated that ripening fruit/grain and increasing grain production is highly dependent on the nutrient P. This indirectly emphasizes that the interaction between humic acid and AMF synergizes in increasing soybean production in Ultisols.

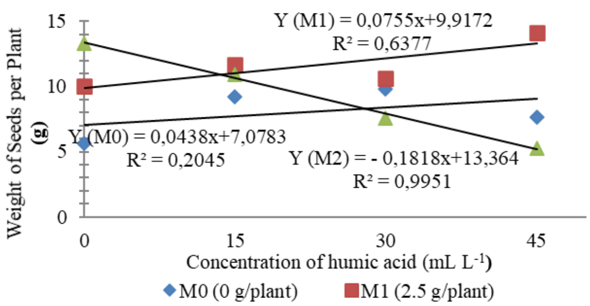

Figure 6. Relationship of humic acid concentration and weight of seeds per plant at several AMF doses

Further tests for the number of root nodules and the weight of dray stover from the humic acid concentration are presented in Figures 7 and 8.

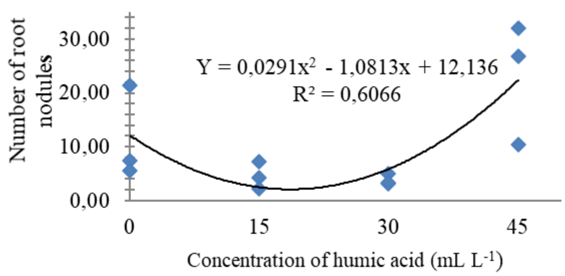

Figure 7. Relation of humic acid concentration and number of root nodules

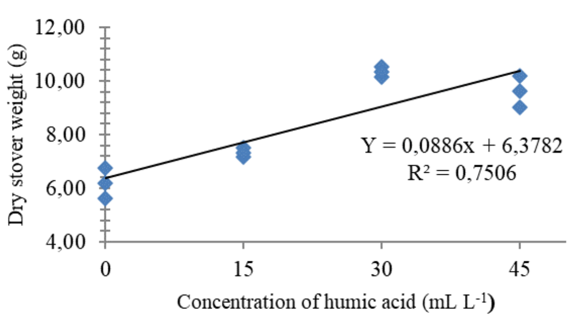

Figure 8. Relationship of humic acid concentration and dry stover weight

The relationship between the number of nodules and the humic acid concentration of 0-45 mL L^{-1} formed a parabolic quadratic pattern with the equation $Y = 0.0291x^2 - 1.0813x + 12.136$. Giving the optimum concentration of humic acid, namely 18.57 mL L^{-1}, will provide a minimum value for the number of nodules. The degree of determination of this equation is $R^2 = 0.6066$. It means that the equation can explain 60.6% of the number of nodules' variability from the concentration of humic acid for the number of nodules (Figure 7).

A large number of nodules do not necessarily indicate good results for the plant. Root nodules will have a positive value if the root nodules are healthy or effective at tethering N. Conversely, a large number of root nodules that are not effective at fixing N will inhibit the growth and yield of soybean plants. The infectivity and effectiveness of natural Rizhobium in soybean plants. However, infection of all Rizhobium strains in acidic soils very slow, especially at pH 4.5 or lower (Taufik & Sundari, 2003). Although the humic acid application has shown an increase in soil pH, namely 6.07 (Figure 1), it has not positively affected Rizhobium on soybean roots, presumably because the soil conditions have never been planted with legume plants before. Apart from root nodules, humic acid also significantly affected the dry stover weight—further tests on dry stover weight presented in Figure 8.

The humic acid concentration of 45 mL L^{-1} resulted in a maximum dry stover weight of 10.36 g (Figure 8). This result corroborated by Wahyuningsih *et al.* (2016) stated that giving humic acid could increase the dry stover weight of soybean plants. Increased dry stover weight reflects the number of nutrients absorbed by plants. Stevenson (1994) explained in Hermanto *et al.* (2013) explains that one of the importance of humic is the humic fraction can provide nutrients such as N, P, K, and S into the soil and C as a source of energy for soil microbes. The results of this study suggest that the dry stover weight consists of various nutrients that have been provided by humic acid to plants.

In general, humic acid independently has no significant effect on yield variables commonly. Meanwhile, in terms of seed weight per plant, the highest yield was obtained from the humic acid concentration of 15 mL L^{-1}, amounting to 10.6 g $plant^{-1}$ or equivalent to a 1.59 tons ha^{-1} production. If compared with the variety description, this result is 21.67% lower than the real potential that is between 2.03-2.25 tons ha^{-1}. However, giving humic acid to Ultisol increased the yield 9.95% higher than without humic acid administration.

The relation between AMF and root colonization, number of seeds per plant, and dry stover weight presented in Figures 9, 10, and 11.

Inoculation of AMF 0-5 g $plant^{-1}$ to the percentage of root colonization forms a quadratic pattern relationship, with the equation $Y = -2,8x^2 + 22x + 21,25$. The percentage of root colonization increased as the AMF dose was increased to the optimum dose, at 3.92 g plant^{-1}. The optimum dose has the potential to produce a percentage of root colonization of 64.46%. Inoculation of AMF above the optimum dose will decrease the percentage of colonization by 2.8%. The coefficient of determination (R^2) of 0.9728 indicates that the AMF quadratic function can determine 97.28% of the variability in the percentage of root colonization. In other words, 2.72% of colonization was caused by influences outside the treatment factors (Figure 9).

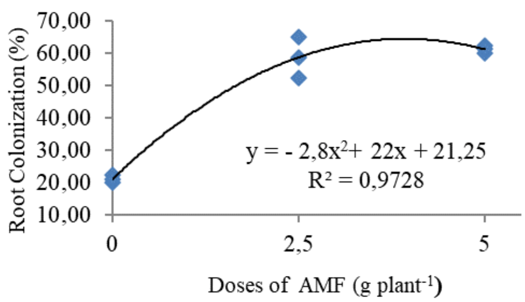

Figure 9. Relationship of AMF and root colonization

Root colonization is a form of the symbiotic process between the host plant roots and AMF (Muryati *et al*., 2016). Root colonization as an important role in the performance of the roots in absorbing nutrients. Besides affecting root colonization, AMF inoculation also significantly affected the number of seeds per plant and dry stover weight. The relationship of AMF inoculation to the number of seeds per plant is presented in Figure 10.

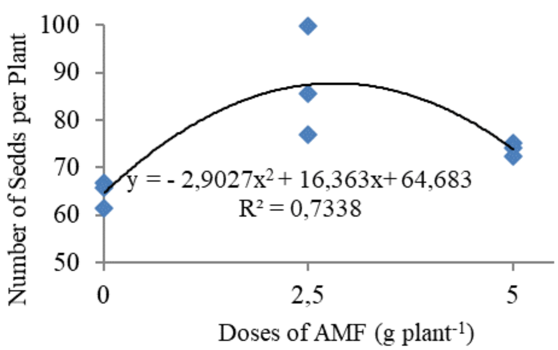

Figure 10. Relationship of AMF and number of the seeds

Inoculation of AMF 0-5 g plant^{-1} to the number of seeds per plant formed a quadratic pattern following the equation Y = $-2{,}9027x^2 + 16{,}363x + 64{,}683$. Indicated that the number of seeds per plant could increase to the optimum point of AMF at a dose of 2.81 g plant^{-1}, potentially producing a total number of seeds per plant as much as 87.74 seeds. Inoculation of AMF above the optimum dose will reduce the number of seeds by 2.9 seeds. The value of the degree of determination R^2 is 0.7338 indicates that 73.38% of the variability of the number of seeds per plant can be determined by the AMF dose equation (Figure 10). This result is indirectly in line with the research of Sabilu *et al*. (2015) stated that the number of seeds per soybean plant with the same variety on Ultisols soil with the provision of 30 g mycorrhizae, namely 83 seeds. However, from an economic point of view, the AMF inoculation of 2.81 g plant^{-1} was effective enough to obtain the maximum number of seeds in Ultisols soil.

Apart from the number of seeds planted, AMF also significantly affected the dry stover weight, presented in Figure 11. The orthogonal polynomial test on dry stover weight from AMF doses at 0-5 g plant^{-1} formed a positive linear response pattern. The equation is Y = 0.5459x + 7.0062, meaning that the dry stover weight will increase by 0.5642 g as the AMF dose increased also. The coefficient of determination R^2 = 0.5617, meaning that 56.17% of the variability of dry stover weight can be determined from the AMF equation (Figure 11). Plant dry weight from AMF inoculation will continue to increase with increasing AMF dose, meaning that AMF positively affects plant dry weight. That is presumably due to infection by AMF, a significant of AMF inoculation on the percentage of root colonization (Figure 9). AMF helped absorb immobile nutrients such as P to use as a plant metabolic process in Ultisol (Malik, 2017).

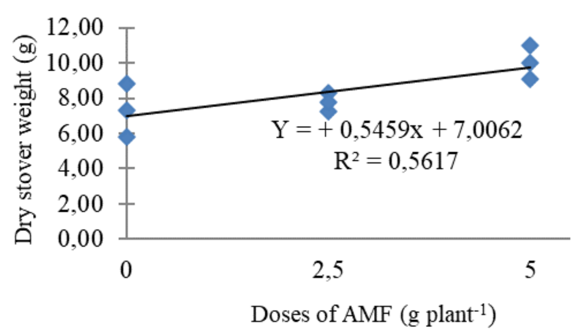

Figure 11. Relationship of AMF and dry stover weight

In general, the yield of soybean from AMF inoculation tends to be high at a dose of 2.5 g plant^{-1}. The highest seed weight per plant was 2.5 g plant^{-1}, amounting to 11.62 g or equivalent to 1.74 tons ha^{-1}. When compared with the yield potential in the variety description, between 2.03-2.25 tons ha^{-1}, the yield from this research is still 14.28% less towards the actual yield potential of soybeans. However, inoculation AMF 2.5 g plant^{-1} in Ultisol obtained 44.16% higher results than without AMF inoculation.

Inoculation of AMF independently in this study did not run optimally on the growth and yield of soybeans. It means that to be due to the less than optimal AMF performance, but there is a possibility that the nutrient is indeed in small amounts in Ultisol soil. In terms of the results obtained, AMF inoculation when compared to humic acid administration. AMF inoculation tended to give superior results than the administration of humic acid independently. The status of AMF as a microorganism can produce nutrients that are useful for plants. The AMF gets its energy from the application of organic fertilizers, with cow manure applied before planting. In another case, the humic acid is not a kind of fertilizer. Still, as a chemical element, it just interacts intensively with soil chemical properties and carries little nutrients to plants. The amount of nutrients humic acid can extract depends on the matter of humic acid was made and the total nutrient content stored in the soil. In other words, the independent application of humic acid must be accompanied by an adequate intake of additional nutrients in less fertile soils.

CONCLUSION

The interaction of 45 mL L^{-1} humic acids at AMF 2.5 g $plant^{-1}$ inoculation was the optimum concentration for growth and yield of soybean in Ultisols. The yield potential obtained is equivalent to 1.99 tons ha^{-1}. The interaction is still 1.97% less than the potential production of soybean in Ultisols. The administration of humic acid or AMF independently at this research stage had not yet given a maximum response to the growth and yield of soybean in Ultisol.

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