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Effect of Arbuscular Mycorrhyzal Fungi in Improving Soybean Growth in Ultisol Soil

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ABSTRACT

Background: Soybean is one of the most popular agricultural commodities in Indonesia, but its production is still low. Thus, it is necessary to make efforts to expand its agriculture in the form of marginal land development.
Aims: This study aims to examine the effect and obtain the best treatment dose of arbuscular mycorrhizal fungi (AMF) in ultisol soil to increase the growth of soybean plants (*Glycine max* (L.) Merill).
Methods: This experimental study employed a complete randomized design (CRD) with the treatment of arbuscular mycorrhizal fungi (AMF). The AMF treatment comprised five levels: no AMF, 4 g/polibag, 8 g/polibag, 12 g/polibag and 16 g/polibag. Each treatment was repeated four times, resulting in 20 experimental units and each experimental unit comprised three polybags so that this study used 60 polybags. The data were analyzed using Analysis of Variance (ANOVA) and continued with Duncan's New Multiple Range Test (DNMRT) at the 5% level.
Result: AMF treatment is able to increase the growth of soybean plants in the parameters of plant height, number of productive branches, flowering age, number of flowers, and harvest age. The AMF treatment dose of 12 g/polybag is proven to give the best results in increasing the growth of soybean plants. The use of AMF can be an effective strategy in optimizing soybean production, especially on marginal lands.

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1. Introduction

Soybean (*Glycine max* (L.) Merrill), a globally important food commodity after rice and corn, is classified as a legume plant, which is a source of protein, fat, and vitamins. The high nutritional value and affordable price make soybeans a food that has been in great demand (Pulukadang *et al.,* 2023). The soybean demand domestically is around 2.2 million tons/year, but its production in Indonesia still has not met the national demand. Domestic soybean production is still very low; in 2023, soybean production is only around 349.09 thousand tons (Directorate General of Food Crops, 2024). Soybean production in Indonesia has only been able to meet 40% of national needs so that the remaining 60% has to be imported from abroad (Statistics Indonesia, 2022). Since the last decade, soybean has been in the spotlight of the Ministry of Agriculture due to the increasing demand along with the increasing population in many regions in Indonesia, such as Riau Province.

Soybean production, specifically in Riau Province for the last five years, has also been low and unstable. Riau Province's soybean production in 2019 was 925 tons/year; in 2020, it increased to 2,854 tons/year; in 2021, it decreased to 957 tons/year; in 2022, there was a noticeable decrease to 334 tons/year; and in 2023, there was a slight increase to 364 tons/year (Directorate General of Food Crops, 2024). This decline in soybean production is a result of the decreasing land area available for soybean cultivation. The soybean cultivation land area in Riau Province was relatively small and fluctuated from 2019 to 2023. In 2019, the soybean land area was 604 ha; in 2020, there was a significant increase to 1,855 ha; but in 2021, the land area decreased again to 684 ha; then in 2022, there was another decrease to 387 ha; and in 2023, the soybean land area experienced a slight increase to 448 ha (Directorate General of Food Crops, 2024). One of many efforts that can be implemented to increase soybean production is the development of cultivation land. Potential agricultural land is increasingly limited so that its expansion can only be conducted on marginal lands, such as ultisol soil.

Ultisol is one type of soil in Indonesia with a wide distribution, reaching 45,794,000 ha or about 25% of the country's total land area. Its largest distribution is in Kalimantan (21,938,000 ha), followed by Sumatra (9,469,000 ha), Maluku and Papua (8,859,000 ha), Sulawesi (4,303,000 ha), Java (1,172,000 ha) and Nusa Tenggara (53,000 ha). This soil can be found in various types of topography, ranging from flat to mountainous land (Rifki *et al.,* 2022). Ultisol is an old soil with an advanced level of weathering so that it is considered poor in terms of nutrient content. In addition, ultisol soil has been used continuously, without paying attention to organic matter management (Arman *et al.,* 2020). The low quality of ultisol soil is characterized by high soil acidity, low cation exchange capacity (CEC), low base saturation, and high Al saturation (Hati, 2023). This also emphasizes the importance of proper soil management to improve ultisol fertility.

One of many efforts to overcome these problems is the development of fertilization technology. The commonly used technology in this case is biofertilizer by utilizing soil microorganisms, such as arbuscular mycorrhizal fungi (AMF). Fertilization using AMF is highly potential to increase the growth and development of soybean plants. According to Sidhu & Lynch (2024), cortex cells of plant roots infected by AMF are not only exhibits larger size, but also have thicker cell walls with altered characteristics, including increased cellulose and hemicellulose content. Moreover, Zhang *et al.* (2023) stated that AMF treatment improves plant water status and nutrient uptake as well as improves soil nutrient stoichiometry, which contributes to increased plant growth. AMF has an important role because it helps in the absorption of both macro and micronutrients and increase plant resistance to pathogen attacks so that plants can live in extreme conditions. Applying AMF to soybean plants will greatly help in increasing nutrient absorption and plant productivity.

Studies concerning the use of AMF has been widely conducted. Lubis *et al.* (2022) stated that AMF treatment can significantly increase phosphorus (P) uptake. Arisma *et al.* (2024) also stated that AMF increases the absorption of P and other microelements, as well as the efficiency of artificial fertilizer use. Furthermore, Pinayungan *et al.* (2021) reported that the AMF treatment dose of 10 g per plant has a significant effect on the growth and yield of tomato plants compared to those of lower doses. This indicates that the higher doses of AMF treatment have potential to give better results for soybean plants. Therefore, it is necessary to conduct a study to examine the effect of AMF treatment on the growth of soybean plants in ultisol soil by employing various AMF doses to obtain the best AMF dose to increase the growth of soybean plants in ultisol soil.

2. Methods

The materials used in this study were Anjasmoro soybean seeds, ultisol soil, arbuscular mycorrhizal fungi (AMF) biofertilizer obtained from Andalas University, Padang, West Sumatra, with sand as the carrier medium, *Rhizobium*, urea fertilizer, rock phosphate (RP) fertilizer, KCl fertilizer, dolomite ($CaMg(CO_3)_2$), water, Dupont Lannete 40 SP, Dithane M-45 fungicide, and polybags measuring 35 x 40 cm.

The tools used in this study were hoe, sieve measuring 20 mesh, sickle, machete, knife, analytical scales, meter, hand sprayer, paddle, paranet, ruler, wood, bucket, marker, label, scissors, stationery, and documentation tools.

This study was conducted experimentally using a completely randomized design (CRD) with AMF treatment. There were five levels of AMF treatment: M0 = No AMF, M1 = 4 g/plant polybag, M2 = 8 g/polybag, M3 = 12 g/polybag, and M4 = 16 g/polybag. Each treatment was repeated four times, resulting in 20 experimental units. Each experimental unit consisted of three polybags so that this study used 60 polybags in total. The data were analyzed using Analysis of Variance (ANOVA) and continued with Duncan's New Multiple Range Test (DNMRT) at the 5% level.

3. Results and Discussion

3.1 Plant Height

The ANOVA results show that AMF treatment significantly affects the height of soybean plants. Table 1 shows the height of soybean plants based on the DNMRT results at the 5% level.

Table 1. Average height of soybean plants with AMF treatment.

AMF Treatment (g/polybag)	Plant Height (cm) (35 DAP*)
0	29.37 b
4	32.69 ab
8	33.84 a
12	34.89 a
16	35.63 a

*Note: Numbers followed by the same lowercase letters in the same column indicate non-significant difference based on the DNMRT results at the 5% level. (*DAP: days after planting)*

Table 1 shows that plant height increases with the AMF treatment dose of 8 g/polybag, which is 1.15 higher than that of without treatment (control). The increase is higher with the AMF treatment doses of 12 and 16 g/polybag, which are 1.19 and 1.21 times higher than that of control, respectively. This is due to the high infection of the roots of soybean plants in the AMF treatment. High infection will increase the capacity of nutrient absorption in the soil. This is in line with Damayanti *et al.* (2023)'s findings, which suggested that AMF treatment increases plant height, especially at 100% recommended dose of NPK fertilizer. This is because the root system of soybean plants in symbiosis with AMF shows better performance owing to the presence of AMF hyphae, which are very fine and long compared to that of root hairs. This enhancement allows the roots of soybean plants to absorb water and nutrients in larger quantities.

Arisma *et al.* (2024) stated that AMF plays an important role in increasing the availability of nutrients for horticultural plants. The symbiosis between AMF and plants increases the absorption of nutrients, such as phosphorus (P), nitrogen (N), and potassium (K), and increases drought tolerance, which facilitates efficient plant growth and soil health. This is also proven by Eliyani *et al.* (2022)'s study, which showed that mycorrhizal treatment increases P uptake, growth, and production of tomato plants. Increased P uptake contributes to increased efficiency of N use by plants. In addition to P and N, AMF treatment can also increase K uptake. Eliyani *et al.* (2022) showed that AMF treatment significantly increases the concentration of nitrogen (N), phosphorus (P), and potassium (K) in tomato plants. Rahman *et al.* (2025), stated that K element is able to increase the stability of cell membranes, reduce cellular damage, and increase the activity of enzymes associated with photosynthesis, which contributes to increased plant growth.

Based on Table 1, the plant height produced is still far below that of standardized national demand, which ranges from 64 to 68 cm. This is thought to be due to several factors that are less supportive in the growth process of soybean plants. Plant response to AMF treatment is not only determined by its characteristics and AMF, but also by other supporting factors that play significant roles. The effectiveness of AMF in increasing plant growth is influenced by soil environmental factors, which include abiotic factors (nutrient concentration, pH, moisture content, pesticides, fertilizers, temperature, and tillage) and biotic factors (microbial interactions, fungal species, host plants, infections that occur, and competition among fungi). Bryant & Bever (2024) stated that the effectiveness of AMF is highly dependent on host specifications and environmental conditions. In addition, not all types of plant respond positively to AMF treatment, since this condition is not only influenced by the effectiveness of isolates and substrate nutrition, but also largely by the level of plant dependence on AMF.

3.2 Number of Productive Branches

The ANOVA results show that AMF treatment significantly affects the soybean plants' number of productive branches. Table 2 shows the soybean plants' number of productive branches based on the DNMRT results at the 5% level.

Table 2. Average soybean plants' number of productive branches with AMF treatment.

AMF Treatment (g/polybag)	Number of Productive Branches (37–42 DAP)
0	2.50 d
4	3.13 c
8	3.63 bc
12	4.00 ab
16	4.38 a

Note: Numbers followed by the same lowercase letters in the same column indicate non-significant difference based on the DNMRT results at the 5% level.

Table 2 shows that the number of productive branches increases with the AMF treatment dose of 4 g/polybag compared to that of without treatment (control). The increase is noticeable with the increasing treatment doses given, namely 8, 12, and 16 g/polybag. This shows that AMF treatment is able to increase the number of productive branches and can supply sufficient amounts of both macro and micronutrients so that they can be absorbed and utilized by plants in the process of vegetative growth, including to increase the number of productive branches.

Sudirman *et al.* (2023) stated that AMF treatment is able to increase the number of plant branches compared to those of without AMF treatment. This is because AMF-treated plants experience an increasing ability to absorb nutrients so that the metabolic process for their growth becomes better.

This aligns with Xiao *et al.* (2023)'s study, which showed that AMF treatment improves plant water status and nutrient absorption as well as improves soil nutrient stoichiometry, all of which contributes to increased plant growth.

Lubis *et al.* (2024) showed that AMF treatment significantly increases P uptake by plants. Hyphae formed by AMF in the soil can absorb P more effectively and transport it to the colonized roots, where P is then transferred to the AMF host. Likewise, Rajmi *et al.* (2020)s' study showed that AMF treatment can increase P availability in ultisol soil by 38.57% compared to that of without AMF treatment. This is important because P is an essential nutrient whose availability in ultisol soil is often limited. The presence of AMF helps plants to more effectively absorb nutrients, including P, since this element is useful for forming pods and accelerating pod maturity. The sufficient amount of absorbed nutrients by soybean plants enable them to photosynthesize well and produce enough assimilate for their growth so that it will spur the formation of productive branches.

3.3 Flowering Age

The ANOVA results show that AMF treatment has a significant effect on the flowering age of soybean plants. Table 3 shows the flowering age of soybean plants based on the DNMRT results at the 5% level.

Table 3. Average flowering age of soybean plants with AMF treatment.

AMF Treatment (g/polybag)	Flowering Age (37–42 DAP)
0	41.33 a
4	40.58 a
8	39.58 b
12	38.66 b
16	37.66 c

Note: Numbers followed by the same lowercase letters in the same column indicate non-significant difference based on the DNMRT results at the 5% level.

Table 3 shows that the flowering age of plants is accelerated with the AMF treatment dose of 8 g/polybag compared to that of control. The acceleration is statistically noticeable with the higher dose given, namely 8, 12, and 16 g/polybag. This is because the AMF treatment dose of 16 g/polybag is able to supply nutrients in greater quantities and is utilized by plants in increasing the rate of plant growth and development, including in stimulating plant generative growth. In addition, this is thought to be due to the presence of AMF infecting plant roots, which results in a better supply of nutrients to the top area of the plant so as to accelerate the average flowering age, which leads to faster harvest age (Table 5). Damayanti *et al.* (2023) suggested that AMF treatment give a better growth response than those of without AMF treatment. This is because AMF can effectively increase the absorption of macronutrients (N, P, K, Ca, and Mg), especially P, as well as micronutrients (Cu, Zn, and Mo).

The flowering age of soybean plants is influenced by the availability and uptake of P nutrients because P functions in flower formation. AMF treatment can increase the P uptake by soybean plants, leading to the acceleration of flowering age. Mane (2020) stated that the P treatment dose of 50 kg/ha produces the highest number of flowers per plant, number of flowers per plot, and number of seeds per flower, as well as optimal seed yield per plant and per hectare. Erviana *et al.* (2023) stated that the treatment of P fertilizer at a dose range of 100–200 kg/ha results in a flowering time of about 34.42 days after planting, which is faster than that of control and can accelerate the flowering age of soybean plants. The speed of flowering age is also influenced by the rate of assimilate translocation because assimilate is needed for the plant development process. The rate of this translocation is influenced by

K nutrient contained in plant tissues. AMF treatment can increase the K uptake by soybean plants, leading to the acceleration of flowering age.

3.4 Number of Flowers

The ANOVA results show that AMF treatment significantly affects the soybean plants' number of flowers. Table 4 shows the soybean plants' number of flowers based on the DNMRT results at the 5% level.

Table 4. Average soybean plants' number of flowers with AMF treatment.

AMF Treatment (g/polybag)	Number of Flowers (37–42 DAP)
0	18.00 b
4	18.75 ab
8	20.25 ab
12	21.00 ab
16	22.50 a

Note: Numbers followed by the same lowercase letters in the same column indicate non-significant difference based on the DNMRT results at the 5% level.

Table 4 shows that the number of soybean flowers increases with the AMF treatment dose of 16 g/polybag. The increase is statistically noticeable with the higher doses given, namely 4, 8, 12, and 16 g/polybag compared to that of control. It is concluded that the higher AMF treatment dose produces the higher number of soybean flowers. This is in line with Mulyana *et al.* (2022)'s findings, which stated that AMF colonization of host plants can increase plant growth, where the combination of AMF and biochar produces optimal growth of soybean plants in saline soils, including an increase in seed yield, which is usually correlated with the higher number of flowers and pods.

AMF treatment to soybean planted in ultisol soil has a positive effect on the number of flowers, because AMF is able to increase P uptake through hyphal extension beyond plant roots. This helps plant roots to reach nutrients that are unreachable in normal condition, which in turn increases plant physiological activities, such as photosynthetic processes and biosynthesis of hormones (e.g., auxins and cytokinins) that stimulate flower initiation and reduce stress caused by environmental conditions (e.g., nutrient deficiency or Al poisoning), which indirectly increases the energy allocated to growth and reproduction. Yunedi & Perdana (2023) reported that AMF treatment in ultisol soil is able to increase the vegetative and generative growth parameters of soybean plants. If the essential nutritional needs of plants are adequately available, plants will experience better growth.

The P uptake by plants in sufficient quantities will result in faster flowering and greater number of flowers. Cinta *et al.* (2022) stated that the dose of P fertilizer has a significant effect on plant height, number of leaves, number of productive branches, and number of empty pods, all of which highlight the role of P in accelerating flowering and pod formation.

3.5 Harvest Age

The ANOVA results show that AMF treatment has a significant effect on the harvest age of soybean plants. Table 5 shows the harvest age of soybean plants based on the DNMRT results at the 5% level.

Table 5. Average harvest age of soybean plants with AMF treatment.

AMF Treatment (g/polybag)	Harvest Age (87–92 DAP)
0	91.50 a
4	90.75 ab
8	89.50 bc

12	89.25 c
16	87.00 d

Note: Numbers followed by the same lowercase letters in the same column indicate non-significant difference based on the DNMRT results at the 5% level.

Table 5 shows that the harvest age of soybean plants is accelerated with the AMF treatment dose of 8 g/polybag compared to that of control. The acceleration is statistically faster with the increasing doses given, namely 8, 12, and 16 g/polybag. This is thought to be due to the presence of AMF, which helps plants in absorbing nutrients, especially P. The shortest harvest age of soybean plants, which is resulted by the AMF treatment dose of 16 g/polybag, is attributed to the large quantity of AMF given to plants, enabling it to sufficiently accelerate the harvest age of soybean plants. This happens because of the availability of macronutrients, mainly P and K, supplied by AMF. AMF treatment can increase the P uptake, leading to the acceleration of harvest age. Islam *et al.* (2023) stated that the sufficient P uptake increases plant vegetative and reproductive growth, including an increase in the number of flowers and seeds. AMF treatment in ultisol soil is proven to has a positive effect on the harvest age of soybean plants.

Through increased P uptake and plant physiological improvement, AMF helps accelerate the transition from vegetative to generative phase and accelerates pod maturation. This makes AMF a strategic environmentally friendly technology in soybean cultivation on marginal land. Mulyana et al. (2022) in a study conducted on saline soil condition, which is also classified as marginal land like ultisol soil, found that the combination of AMF and biochar increases soybean yield and accelerates pod formation. This shows the tendency of earlier harvest age owing to AMF treatment. The speed of harvest age is also influenced by the rate of assimilate translocation because assimilate is needed for the plant development process. The rate of this translocation is influenced by K nutrient contained in the plant tissue. AMF treatment can increase the K uptake by soybean plants, leading to the acceleration of harvest age.

4. Conclusions

AMF treatment is able to increase the growth of soybean plants, namely in the parameters of plant height, number of productive branches, flowering age, number of flowers, and harvest age. The best AMF treatment dose is 12 g/polybag, since it is proven to give the best results in increasing the growth of soybean plants. The use of AMF can be an effective strategy in optimizing soybean production, especially on marginal land, such as ultisol soil in this case. However, based on this study's findings, the growth yields of soybean plants are still far below those of standardized national soybean demand so that further studies needs to be conducted to explore the more effective methods in enhancing soybean plant growth.

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