

Phosphate Uptake, Mycorrhiza Colonization and Yield of Soybean on Ultisols Affected by Water Stress and Mycorrhiza

Penyerapan Fosfat, Kolonisasi Mikoriza dan Hasil Kedelai pada Ultisol yang Terkena Stres Air dan Mikoriza

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ABSTRACT

Mycorrhizal symbiosis can enhance nutrient uptake, especially phosphorus, by plants and increase plants' drought resistance as well. An experiment was set up to investigate the effects of water stress and mycorrhizal inoculation on phosphate uptake, mycorrhizal colonization, growth, and the yield of soybean. The experiment design used was Factorial Randomized Block, which consisted of two factors. The first factor was water stress, which consisted of three levels, i.e., 100 % field capacity; 75 % field capacity, and 50 % field capacity. The second factor was mycorrhiza, which consisted of three levels, i.e., without mycorrhizal inoculation, 10, and 20 g of mycorrhizal inoculant. The experiment consisted of two units with three replications; the first unit was harvested at the end of the vegetative period to observe plant uptake of phosphorus, percentage of mycorrhizal infection, and dry weight of soybean, and the second unit was harvested at the end of the generative period to find out the yield of soybean. The results of this experiment showed that there was no interaction effect between water stress and mycorrhizal inoculation on plant uptake of phosphorus, percentage of mycorrhizal infection, dry weight, and yield of soybean. Water stress decreased phosphate uptake, percentage of mycorrhizal infection, dry weight, and yield of soybean. Mycorrhizal inoculation increased phosphate uptake and the percentage of mycorrhizal infection.

Key words: drought; field capacity; mycorrhizal infection; soybean

INTRODUCTION

Ultisols are marginal soils with a fairly wide distribution, but have physical and chemical properties that are less supportive of plant growth. The pH value, which is usually acidic, and the solubility of Al, Fe, and Mn, which are relatively high, are obstacles to plant growth. The high levels of Al, Fe, and Mn in Ultisols can bind the element P to become insoluble and unavailable to plants (Ifansyah, 2013)

Another limiting factor in the utilization of Ultisols is water. Because Ultisols are dry land that is very widespread in Indonesia, handling water needs is an important thing to do on Ultisols soil (Global Forest Watch, 2018). Many efforts have been made to increase the productivity of Ultisols, one of which is by providing P fertilizer to the soil, either in the form of artificial fertilizers or natural fertilizers. To increase fertilization efficiency and save costs, it is necessary to

develop soil biotechnology. The use of mycorrhiza in handling the problem of fertilization efficiency is something that can be done on Ultisols soil, which has a problem of a lack of macro nutrients, especially phosphorus.

Mycorrhiza is a symbiosis between the roots of higher plants and fungi (Sieverding, 1991; Smith & Read, 1997). The main benefit of symbiosis between mycorrhiza and plants is its ability to increase phosphorus nutrient absorption and improve plant growth. The increase in P absorption capacity by mycorrhizal plants can occur directly through the external hyphae network system and indirectly due to changes in root physiology. External hyphae network expands the surface area of absorption further to search for nutrients and water that are relatively inaccessible to the root system (Wahab et al., 2021).

Soybeans are plants that are not drought-tolerant; water is needed from the

beginning of growth until the pod filling period. According to Yang et al. (2023), if the plant experiences drought during the vegetative period, it will inhibit leaf growth, and the plant will shed its leaves. Drought during flowering will also increase the degree of flower loss. During the pod formation period, it will inhibit the formation and shedding of newly formed pods, while water drought during the pod filling period will reduce the number of seeds and the density of seed size. (Aziez et al., 2022)

Plants will experience drought if the rate of groundwater transmission to the surface layer is less than the rate of evapotranspiration. As a result of water shortages, which directly or indirectly affect photosynthesis, which occurs with changes in the metabolic process in the leaves. Furthermore, there is a decrease in turgor, closure of stomata in the leaves, and a decrease in the CO₂ binding process, resulting in decreased photosynthesis results in line with the loss/decrease in water content in the leaves (Nguyen et al., 2023). According to Lumactud et al. (2022), low soil water content has detrimental effects such as decreasing the number of nodules, dry weight of nodules, plant biomass, and nitrogenase activity compared to plants grown at field capacity.

To increase the resistance of soybean plants to drought, biological engineering technology can be used, namely by adding arbuscular mycorrhizal fungi (AMF) to the soil. Mycorrhiza is a symbiosis between the roots of higher plants and fungi (Sieverding, 1991). Based on the method of infection of the host plant, mycorrhiza can be grouped into three groups, namely ectomycorrhiza. Furthermore, Sieverding (1991) stated that AMF play a role in the absorption of macro and micro nutrients, increasing resistance to drought, protecting plants from heavy metal poisoning, protecting

roots from pathogen attacks, and helping plant growth in unfavorable soil conditions. Plants inoculated with AMF have higher nutrient content compared to plants not inoculated with AMF (Zhang et al., 2022).

Nutrient transformation is an important part of the mutualistic symbiosis between mycorrhizal fungi and host plants, where nutrients (especially P) are translocated by mycorrhizal fungi to host plants and organic C (sugar forms) are transferred from host plants to mycorrhizal fungi (Smith & Read, 1997).

Factors that directly or indirectly affect the host plant will affect the growth and development of AMF. The development of AMF is influenced by the sensitivity of the host plant to soil temperature, light intensity, nutrient and soil water content, soil pH, organic matter and root residue, heavy metals, infection, and fungicides (Pfleger & Linderman, 1996). Plants with mycorrhizae are more resistant to drought than plants without mycorrhizae (Smith & Read, 1997).

The potential application of AMF, in addition to increasing P solubility, also increases the efficiency of nutrient absorption (both macro and micro nutrients), increases disease resistance, and can also increase resistance to water stress (Pleger and Linderman, 1996). Therefore, to increase the productivity of Ultisols soil, especially for soybean plants, it is necessary to study the effects of water stress and mycorrhizal administration. This study aims to determine the effect of various soil water levels and mycorrhizal administration on P absorption, mycorrhizal colonization, growth, and yield of soybean plants.

Materials and Methods

The research was conducted in the greenhouse of the Faculty of Agriculture, Universitas Padjadjaran, located in Jatinangor, Sumedang Regency, Indonesia, at an altitude of 700 m above

sea level. The materials used in this study were Ultisols soil from Jatinangor, Sumedang Regency, West Java, which was taken from the composite processing layer. Willis cultivar soybean seeds were obtained from the Garut Seed Certification Center, West Java.

Mycorrhizal inoculum was obtained from the Forestry Biotechnology Laboratory, PAU, Bogor Agricultural University, which is an inoculum containing a mixture of *Glomus manihotis*, *Acaulospora tuberculata*, and *Gigaspora margarita*. The basic fertilizers used were urea (46% N), SP-36 (36% P₂O₅), and KCl (50% K₂O), and liquid organic fertilizer, namely Humega. In addition, chemicals were used for the analysis of plant phosphorus absorption

The experimental design used was a factorial Randomized Block Design, the first factor was water stress (soil water content) consisting of three levels (100%, 75% and 50% field capacity), while the second factor was mycorrhiza consisting of three levels (without mycorrhizal inoculant, 10 grams of mycorrhizal inoculant per pot and 20 grams of mycorrhizal inoculant per pot).

The response variables observed in the final vegetative phase include phosphate uptake, mycorrhizal colonization (degree of root infection), plant growth (plant dry weight), and soybean yield (generative phase). To examine the effect of treatment on the response variable, a univariate analysis was carried out using the F test followed by the Duncan test.

RESULTS AND DISCUSSION

Analysis of Ultisols

Based on the results of the analysis before the experiment, the Ultisols soil from Jatinangor showed acidity of the soil pH which was acidic (5.4), high organic C content (3.11%), moderate total N value (0.31%), moderate K (0.32 mg 100⁻¹ g), moderate total P (18.59 mg 100⁻¹ g), very low Bray I-available P (0.30 mg 100⁻¹ g), moderate base saturation (38%), high CEC (31.50 me 100⁻¹ g), low Al⁺ and H⁺ respectively (0.23 and 0.24 mg 100⁻¹ g), soil texture was clay [clay; dust; sand (70%; 16%; 14%)]

In general, the productivity of Ultisols soil, seen from the chemical properties of the soil (nutrient content), is low, especially phosphorus, so that the provision of mycorrhiza is expected to increase the availability of phosphorus, which then affects plant growth, especially increasing phosphorus absorption.

Judging from the location of the Ultisols soil used in this study, it is located in dry land and areas that have water shortage problems. This is supported by the results of soil physics analysis, which show low soil water content.

Plant P Uptake

Based on statistical analysis, there is no interaction between water stress and mycorrhiza treatments on P uptake in soybean plants. The independent effect of water stress and mycorrhiza treatments on plant P uptake can be seen in Table 1.

Table 1. Effect of Water Stress and Mycorrhiza on P Uptake in Soybean Plants

Treatments	P uptake mg pot ⁻¹
Water Stress	
100 % field capacity	1.45 c
75 % field capacity	1.24 b
50 % field capacity	0.99 a
Mycorrhiza	
without mycorrhiza	1.14 a
10 g mycorrhiza	1.18 a
20 g mycorrhiza	1.36 b

Note: Numbers followed by the same letter are not significantly different according to Duncan's test at the 5% level.

Based on Table 1, it can be seen that the lower the soil water content (the decreasing percentage of field capacity) affects the decrease in plant P absorption. This shows that the decreasing water content can interfere with the reactions that occur in the soil, especially the transformation of nutrients. This condition also affects the mechanism of plant absorption of nutrients, so that the decreasing soil water content will decrease the value of plant P absorption. In such a situation, it turns out that the addition of mycorrhiza is not enough to overcome the decrease in P absorption. Table 1 also shows that plant P absorption increases due to the addition of a mycorrhiza dose of 20 g per plant. This shows that the presence of mycorrhiza symbiosis with plants can help plants in the absorption of macro nutrients, especially phosphorus (Smith and Read, 1997).

Mycorrhizal Infection

Based on the results of statistical analysis, it is shown that there is no interaction between water stress and mycorrhizal treatment on the degree of mycorrhizal infection. The independent effect of water stress and mycorrhizal treatment on the degree of root infection can be seen in Table 2.

From Table 2, it can be seen that the percentage of decreasing field capacity affects the decrease in the degree of root infection. Such conditions indicate that excess or lack of water is suspected of disrupting mycorrhizal growth. According to Tian et al (2025), the quality of mycorrhizae will decrease in conditions that are too wet or too dry. Maximum colonization of mycorrhizal occurs at potential pressures of up to 0.2 bar. Mycorrhizal colonization decreases with decreasing potential water pressure. Meanwhile, the best spore population is obtained in plants that are irrigated every day at field capacity conditions.

Table 2. Effect of Water Stress and Mycorrhiza on Mycorrhizal Infection

Treatments	Mycorrhizal Infection (%)
Water Stress	
100 % field capacity	16.56 b
75 % field capacity	12.89 a
50 % field capacity	9.22 a
Mycorrhiza	
without mycorrhiza	8.89 a
10 g mycorrhiza	13.78 b
20 g mycorrhiza	16.00 b

Note: Numbers followed by the same letter are not significantly different according to Duncan's test at the 5% level.

The data in Table 2 show that mycorrhizal inoculation can increase the degree of root infection. The presence of root infection by mycorrhizae can be influenced by the density of the inoculant spore population. In this case, the addition of 10 to 20 grams per plant can increase the degree of root infection. According to Bellgard (1992), the presence of infection by endomycorrhizae can be characterized by the formation of vesicles and

arbuscules, so it is known as VAM (vesicular-arbuscular mycorrhizae).

Plant Dry Weight

Based on the results of the analysis it shows that there is no interaction between water stress and mycorrhiza treatments on plant dry weight at the end of the vegetative period. The independent effects of water stress and mycorrhiza treatments can be seen in Table 3 below.

Table 3. Effect of Water Stress and Mycorrhiza on Plant Dry Weight

Treatments	Dry Weight (g)
Water Stress	
100 % field capacity	6.39 b
75 % field capacity	5.89 b
50 % field capacity	4.16 a
Mycorrhiza	
without mycorrhiza	5.70 a
10 g mycorrhiza	5.10 a
20 g mycorrhiza	5.63 a

Note: Numbers followed by the same letter are not significantly different according to Duncan's test at the 5% level.

Table 3 shows that the water-stressed conditions affect plant growth in this case, the dry weight of plants in the final vegetative phase. A decrease in soil water content (a decrease in the percentage of field capacity) can actually reduce plant dry weight. It is suspected that the absorption of nutrients is not optimal due to suboptimal environmental conditions (lack of water), so that with the decrease in the capacity of plants to absorb nutrients and water, plant growth and development will decrease.

This is supported by Tasca et al. (2024), that low soil water content has a detrimental effect, such as decreasing the number of nodules, dry weight of nodules, plant biomass, and nitrogenase activity

compared to plants growing in field capacity conditions.

Table 3 shows that the application of mycorrhiza does not increase plant dry weight. This is suspected because the development of mycorrhiza is not optimal due to environmental conditions that are not optimal (water stress). As a result of this water stress, the ability of mycorrhiza to increase plant growth is not optimal.

Yield of Soybean

Based on the results of statistical analysis, it shows that there is no interaction between water stress and mycorrhiza treatments on soybean plant results. The independent effects of water stress and mycorrhiza treatments on soybean plant results can be seen in Table 4.

Table 4. Effect of Water Stress and Mycorrhiza on the Yield of Soybean

Treatments	Yield (g)
Water Stress	
100 % field capacity	5.25 b
75 % field capacity	4.57 a
50 % field capacity	3.95 a
Mycorrhiza	
without mycorrhiza	4.46 a
10 g mycorrhiza	4.45 a
20 g mycorrhiza	4.84 a

Note: Numbers followed by the same letter are not significantly different according to Duncan's test at the 5% level

From Table 4, it can be seen that water stress treatment affects soybean yields. The lower the soil water content (50% field capacity), the lower the soybean yield. This is thought to be due to a lack of water in the soil affecting plant growth and development. It is known that plant metabolism is influenced by the availability of water. Therefore, reduced water in the soil will reduce soybean yields. The effect of mycorrhizal administration did not affect soybean yields. It is thought that the development of mycorrhizae is not optimal due to the influence of a suboptimal environment (in this case, water stress).

CONCLUSIONS

Based on the results of this experiment, it can be concluded that there is no interaction between water stress and mycorrhizal treatments on P absorption, degree of root infection, dry weight, and soybean plant yield. Decreasing the percentage of field capacity (up to 50% of field capacity) significantly reduces P absorption, the degree of root infection, dry weight, and soybean plant yield. Mycorrhizal inoculation significantly increases plant P absorption and the degree of root infection.

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REFERENCES

- Aziez, AF., Prasetyo, A., Paiman. 2022. Root Growth Response of Soybean (*Glycine max* L.) Under Water Deficit. *Journal of Biodiversity and Biotechnology*. 2(2), 63–69. doi: <http://dx.doi.org/10.20961/jbb.v2i2.66465>
- Bellgard, S.E. 1992. The propagules of vesicular-arbuscular mycorrhizal (VAM) fungi are capable of initiating VAM infection after topsoil disturbance. *Mycorrhiza* 1(4):147-152. DOI: 10.1007/BF00203288
- Global Forest Watch (June, 2018). Indonesian Soil Types. retrieve from: http://gfw2-data.s3.amazonaws.com/country/idn/zip/idn_soil_type.tif.zip.
- Ifansyah, H. 2013. Soil pH and Solubility of Aluminum, Iron, and Phosphorus in Ultisols: the Roles of Humic Acid. *J.Trop. Soil*. 18 : 3. 203-208. DOI: 10.5400/jts.2013.18.3.203.
- Nguyen, T.B., Cecile Lefoulon, C., Nguyen, TH., Blatt, MR., Carroll, W. 2023. Engineering stomata for enhanced carbon capture and water-use efficiency, *Trends in Plant Science*. 28: 11

- <https://doi.org/10.1016/j.tplants.2023.06.002>
- Lumactud, R.A., Dollete, D., Liyanage, D.K., Hill, B., Thilakarathna, M. 2022. The effect of drought stress on nodulation, plant growth, and nitrogen fixation in soybean during early plant growth. *Journal of Agronomy and Crop Science*. 209(3). DOI: 10.1111/jac.12627
- Pleger, F.L. dan Linderman, R.G. 1996. *Mycorrhizae and plant health*. APS Press. The American Phytopathological Society, St. Paul, Minnesota.
- Sieverding, E. 1991. Vesicular-arbuscular mycorrhiza management in tropical agrosystems. Technical Cooperation, Federal Republic of Germany.
- Smith, S.E. dan D.J. Read. 1997. *Mycorrhizal symbiosis*. Academic Press. Harcourt Brace & Company, Publishers. San Diego, London NewYork Boston, Sydney, Tokyo, Toronto.
- Tasca, H.C., Posso, D.A., Mossi, A.J., Bayer, C., Cansian, R.L., Chavarria, G., Sausen, T.L. 2024. Impact of Nodulation Efficiency and Concentrations of Soluble Sugars and Ureides on Soybean Water Deficit During Vegetative Growth. *Nitrogen*. 5, 992–1000. <https://doi.org/10.3390/nitrogen5040063>
- Tian, K., Claire Farrell, C., Anna Lintern, A., Palacios, Y.M., Szota, C., Winfrey, B. 2025. Does mycorrhizal colonization of biofilter plants improve their water uptake or drought resistance?. 2025. *Urban Forestry & Urban Greening* 104, 128643. www.elsevier.com/locate/ufug
- Wahab, A., Muhammad, M.M., Munir, A., Abdi, G., Zaman, W., Ayaz, A., Khizar, C., Reddy, S.P.P. 2023. Role of Arbuscular Mycorrhizal Fungi in Regulating Growth, Enhancing Productivity, and Potentially Influencing Ecosystems under Abiotic and Biotic Stresses. *Plants*. 12, 3102. <https://doi.org/10.3390/plants12173102>
- Yang, X., Lu, M., Wang, Y., Wang, Y., Liu, Z., Chen, S. 2021. Response Mechanism of Plants to Drought Stress. *Horticulturae*. 7, 50. <https://doi.org/10.3390/horticulturae7030050>
- Zhang W, Yu L, Han B, Liu K, and Shao X. 2022. Mycorrhizal Inoculation Enhances Nutrient Absorption and Induces Insect-Resistant Defense of *Elymus nutans*. *Front. Plant Sci*. 13:898969. doi: 10.3389/fpls.2022.898969