Effects of NPK and mycorrhizae on the growth, P uptake of soybean, and soil chemist in peatland, Pelalawan, Riau

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Abstract. Peatlands have great potential if they are used as agricultural lands. However, more attention is necessary for the management of water, soil pH, and the provision of nutrients. This research was conducted to determine the growth and P uptake of soybean plants on peatland as affected by fertilizer treatment and mycorrhizae application in soybean plants. The study was conducted in the peatland of Pelalawan Village, Pelalawan District, Pelalawan Regency, Riau using soybean plants cultivar Anjasmoro. The research was arranged in a complete randomized complete block design consisting of two factors. The first factor was fertilizer treated, comprising N1 (no fertilizer), N2 (150 kg ha\(^{-1}\) compound NPK fertilizer), and N3 (300 kg ha\(^{-1}\) compound NPK fertilizer). Meanwhile, the second factor was application of mycorrhizae comprising M1 (without mycorrhizae) and M2 (with mycorrhizae). Each treatment combination consisted of three replications. The data were analyzed with analysis of variance at a 5% confidence level and tested using DMRT test. The results showed that combination of mycorrhizae and NPK 300 kg ha\(^{-1}\) gave the best effect from other treatment on the growth, P uptake of soybean and the soil chemist.

1. Introduction
The need for this soybean commodity continues to increase from year to year because it has many functions as the main food ingredient, animal feed, and as raw materials for small to large scale industries. However, the high demand for domestic soybeans has not been able to be met by domestic soybean production. New domestic soybean production can only meet the needs of around 30 percent, while at least 70 percent must be imported [4]. The opportunity to increase domestic soybean production is still wide open, both through increasing productivity and expanding planting areas.

Soil, as a growing medium for plants, plays an important role greatly affecting plant growth. The level of soil fertility can be seen based on three properties, namely physical properties, chemical, and biological properties. Recently, fertile land for agricultural development is increasingly limited due to the conversion of productive agricultural land. The conversion more functions of agricultural land are being turned into non-agriculture can certainly reduce soybean production so that the extensification of agricultural land is necessary, one of which is leading to marginal lands including peatlands [15]. The use of peatland as a soybean planting area is one of the alternatives taken by the government today as an effort to increase domestic soybean production. Peatlands in Indonesia have good potential to be used as agricultural cultivation land. However, the use of peatlands is not easy because it has quite a lot of obstacles which can cause low productivity. Some of the things that make peat soil not easy to use as agricultural land include the varying maturity and thickness of peat, the decrease in peat surface, the low bearing capacity, low soil fertility, the presence of pyrite and sand, very acidic soil pH, the conditions of peatland which is water-saturated (inundated) in the rainy season and dried during the dry season, and the susceptibility to fire [15]. Various efforts are made to increase the potential of peatlands for crop cultivation. Fulfillment of nutrient needs through fertilization is one of the efforts that can be made to increase the availability of nutrients in the soil in meeting the nutrient needs of plants cultivated on peatlands.
In addition to the expansion of planting areas, the productivity of soybean plants can also be increased by the use of mycorrhiza as an agent that helps absorb nutrients in plant roots through the hyphae tissue they have [16]. External hyphae tissue from mycorrhiza will expand the area of water and nutrient uptake. The finer size of hyphae from root hairs allows hyphae to infiltrate the smallest (micro) soil pores so that hyphae can absorb water in very low soil moisture conditions [4]. The presence of mycorrhizae in the cultivation of plants on peatland can increase the inorganic P uptake by plants because the hyphae of mycorrhizal fungi that live in the root zone also emit phosphatase enzymes that are capable of transforming organic P into inorganic P thereby increasing P availability for plants. [12] said that the main function of hyphae is to absorb air from the soil, P that accumulates in external hyphae will soon be converted into polyphosphates by using the enzyme phosphatase. This condition causes inorganic P released from organic P on the cell surface so that it can be absorbed through changes in nutrient uptake [13].

The relationship between the function of mycorrhiza, fertilization, and the natural conditions of peat that is less optimal in its utilization as a crop cultivation area is interesting to be further studied. This research was conducted to determine the effect of the application of NPK fertilizer and mycorrhizae on the growth and P uptake of soybean plants in Pelalawan peatland, Riau.

2. Materials and methods
The steps of field research included land preparation, planting, maintenance, observation, sampling, and harvesting. Meanwhile, the steps of laboratory research consisted of sample preparation and analysis of both soil samples and tissue samples. The research was arranged in a randomized complete block design (RCBD) consisting of two treatment factors, namely the application of mycorrhizae and compound NPK fertilizer. The application of mycorrhizae consisted of two levels without mycorrhizae (M1) and given mycorrhizae (M2), and the application of compound NPK fertilizer consisted of three doses 0 kg ha\(^{-1}\) (N1), 150 kg ha\(^{-1}\) (N2), and 300 kg ha\(^{-1}\) (N3). The experimental field was first given dolomite lime with a dose of 300 kg ha\(^{-1}\). Before planted, the seeds were treated with mycorrhizae fungi. The sampling of soil and tissue treatment was carried out when the plant entered the maximum vegetative phase, while the initial soil sampling was carried out before the planting time. Soil analysis was performed on the variables of pH (H\(_2\)O and KCl), organic C with the ignition method, available P with extractors Bray and Kurtz, Cation Exchange Capacity with 1 M ammonium chloride, available cations with 1 M ammonium chloride, and peat maturity using staining solution of saturated Na-pyrophosphate on chromatograph paper compared to soil Munsell color chart. Meanwhile, tissue analysis was performed on the variables of P uptake in the shoots and roots of the plants. Observation of agronomic traits was made on the plant height, the number of leaves, fresh and dry weight of shoots and roots, and length of the root of soybean plants. The data of the research results were analyzed using analysis of variance (ANOVA) to determine the significant effects of the treatments. If the effect was significant (F count> F table, with α = 5%), the data were tested further using Duncan multiple range test (DMRT) at 5 %.

The chemical properties of Pelalawan peat soil can be seen in Table 1.

| Parameter       | Unit          | Value | Category     |
|-----------------|---------------|-------|--------------|
| Actual pH       | -             | 3.8   | Very acidic  |
| Potential pH    | -             | 3.3   | -            |
| Organic C       | %             | 50.18 | -            |
| Organic matter  | %             | 86.52 | -            |
| CEC             | cmol(+)kg\(^{-1}\) | 19.73 | Medium       |
| K               | cmol(+)kg\(^{-1}\) | 0.26  | Low          |
| Na              | cmol(+)kg\(^{-1}\) | 0.56  | Medium       |
The Initial soil chemical properties of Pelalawan peat soil can be seen in Table 1.

Table 1. Initial soil chemical properties of Pelalawan peatland

| Remarks |
|---------|
| Categories are based on [1]. |

### 3. Results and discussion

#### 3.1 Effects of the application of mycorrhizae and doses of compound npk fertilizer on the soil chemical properties

##### 3.1.1 Actual pH and potential pH

From the results of the analysis of variance obtained in Table 2, it can be seen that the application of mycorrhizae and NPK fertilizer doses did not significantly influence the actual pH of the soil but had a significant effect on the soil potential pH. Peat soil is classified in the category of soil that reacts acidic and has a low pH value.

Table 2. Effects of the application of mycorrhizae and doses of compound NPK fertilizer on the actual and potential soil pH

| Treatments  | pH H₂O   | pH KCl   |
|-------------|----------|----------|
| M1N1        | 4.29 a   | 3.30 ab  |
| M1N2        | 4.28 a   | 3.22 b   |
| M1N3        | 4.35 a   | 3.30 ab  |
| M2N1        | 4.31 a   | 3.26 ab  |
| M2N2        | 4.30 a   | 3.22 ab  |
| M2N3        | 4.51 a   | 3.47 a   |

Remarks: Values followed by the same letters in the same column are not significantly different according to DMRT at 5%.

M1N1= without mycorrhizae+ 0 kg/ha NPK    M2N1= with mycorrhizae + 0 kg/ha NPK
M1N2= without mycorrhizae+ 150 kg/ha NPK M2N2= with mycorrhizae + 150 kg/ha NPK
M1N3= without mycorrhizae+300 kg/ha NPK  M2N3= with mycorrhizae + 300 kg/ha NPK

The highest actual pH value was found in the soil with M2N3 treatment, reaching 4.51, while the lowest actual pH was found in the soil with M1N2 treatment, which was 4.28. The highest potential pH value was found in the soil with M2N3 treatment, which was equal to 3.47, while the lowest potential pH was found in the soil with M1N2 treatment, reaching 3.22. Peat soil is classified as marginal land because, in addition to its low availability, this type of soil is often found to have acidic to very acidic pH. According to [3], peat soil has a relatively high acidity level with a pH range of 3-4.

##### 3.1.2 Soil organic matter

The application of mycorrhizae and doses of NPK fertilizers did not have a significant effect on the content of soil organic matter. The highest value of organic matter content was found in the soil with M1N2 treatment, which was equal to 84.44%, while the lowest organic matter content was found in the soil with M2N2 treatment, reaching 77.78%.

Table 3. Effects of the application of mycorrhizae and doses of compound NPK fertilizer on the organic matter content

| Treatments  | Organic matter (%) |
|-------------|--------------------|
| M1N1        | 83.84 a            |
| M1N2        | 84.44 a            |
| M1N3        | 78.77 a            |
| M2N1        | 81.31 a            |
The high content of organic matter in the peat soil is caused by the formation of peat soil, which is from the accumulation of organic matter, which slowly decomposes due to wetting. It leads to the high content of organic material, reaching more than 30%. 

3.1.3 Cation exchange capacity

The CEC of soil varies according to the type and number of colloids present in the soil such as the type of clay, the amount of clay, and the colloid of organic matter contained in the soil [16]. In peat soil, the colloid of organic matter dominates the influence on the CEC of the soil compared to the presence of other factors such as the type and amount of clay minerals in the soil. This is because the parent material that composes the body of peat soil is an accumulation of organic matter that undergoes a series of geogenic processes.

Table 4. Effects of the application of mycorrhizae and doses of compound NPK fertilizer on the cation exchange capacity

| Treatments  | CEC (cmol(+)/kg⁻¹) |
|-------------|---------------------|
| M1N1        | 24.67 ab            |
| M1N2        | 30.68 a             |
| M1N3        | 28.44 ab            |
| M2N1        | 31.16 a             |
| M2N2        | 22.31 b             |
| M2N3        | 22.63 b             |

Values followed by the same letters in the same column are not significantly different according to DMRT at 5%.

Remarks: Values followed by the same letters in the same column are not significantly different according to DMRT at 5%.

According to Table 4, the application of mycorrhizae and doses of NPK fertilizer gave a significantly different effect on the value of soil CEC. The highest CEC was found in the peat soil treated with M2N1, with a value of 31.16 cmol (+) kg⁻¹, while the lowest CEC value was found in the peat soil with M2N2 treatment, which was 22.31 cmol (+) kg⁻¹. Based on [1], the CEC value of peat soil is classified as moderate to high. The existence of organic matter serves to reduce the zero charge point so that with high organic matter, the colloidal soil content increases and increases the soil CEC [16]. Colloidal organic matter is one of the factors that influence the high CEC value of soil because, on the surface of colloidal organic matter, there are functional groups in the form of carboxyl groups and phenolic groups. Through the process of hydroxyl dissociation from the carboxyl group and phenol groups, colloidal organic matter can produce a negative charge that can increase the ability of the soil to exchange cations. This is consistent with what [5], stating that the negative charge formed is the result of hydroxyl dissociation in the carboxyl group and phenol group. However, this phenomenon does not always happen this way.

[14] said that the environmental pH above pKa will cause protons in the acid to be released all, and if the environmental pH is smaller than pKa, the organic compounds will be acidic and not charged. The influence of environmental pH plays an important role in the process of dissociation of
hydroxyl carboxyl groups and phenol groups. If the pH of the environment is above the pKa of the carboxyl group, the protons in the acid will be released and deprotonated so that the organic matter can be negatively charged. On the contrary, if the environmental pH is lower than the pKa value, the organic compound will be in acidic form and uncharged so that the presence of organic matter is not able to improve the soil CEC.

3.1.4 Available phosphorus
Table 5 presents the available phosphorus content in peat soil after the application of mycorrhizae and doses of NPK fertilizer. Based on the analysis of variance, the application of mycorrhizae and doses of NPK fertilizer did not have a significant effect on the available phosphorus content in the soil.

Table 5. Effects of the application of mycorrhizae and doses of compound NPK fertilizer on the available P

| Treatments   | Available P (mg/kg) |
|--------------|---------------------|
| M1N1         | 0.31 a              |
| M1N2         | 0.47 a              |
| M1N3         | 0.33 a              |
| M2N1         | 0.68 a              |
| M2N2         | 0.80 a              |
| M2N3         | 1.07 a              |

Remarks: Values followed by the same letters in the same column are not significantly different according to DMRT at 5%.

Based on Table 4.8, the highest phosphorus content was found in the peat soil with M2N3 treatment, with a value of 1.07 mg/kg, while the lowest phosphorus content was found in peat soil with M1N1 treatment, reaching a value of 0.31 mg/kg. Based on [1], the phosphorus content is classified as very low with P <4 mg/kg. Elements of phosphorus in the soil can be sourced from weathering rock/parent material as well as the results of the decomposition of organic materials. The availability of phosphorus in peat soil is often a problem that must be considered in agricultural activities. Peat soil has a condition that strongly does not support the availability of P elements, namely low soil pH. Low pH can reduce solubility and availability of P elements due to the high amount of the fixed P elements. The addition of organic matter produces organic compounds in the soil that can increase P availability through the formation of organophosphate complexes that are easily assimilated by plants, the replacement of H₂O anions in the adsorption site, and the covering of Fe/Al oxide by humus that forms a protective layer, reduces P adsorption, and increases the amount of organic P mineralized into inorganic P [17].

3.2 Effects of the application of mycorrhizae and doses of npk fertilizer on the growth of soybean plants

3.2.1 Plant height
Based on Figure 1, it can be seen that each treatment had a different effect on plant height. From the graph, it is known that the highest plant height was found in M2N3 treatment, which is a treatment with the addition of mycorrhizae and the use of NPK fertilizer with a dose of 300 kg ha⁻¹. Meanwhile, the lowest plant height was observed in the M1N1 treatment, which is a treatment without the application of mycorrhizae and NPK fertilizer application. The application of mycorrhizae is not only effective for increasing the absorption of P nutrients in the soil but also effective for increasing other nutrients such as N, K, Ca, Mg which are mobile in the soil [15].

3.2.2 Number of leaves
Based on Figure 2, the highest number of leaves was found in the treatment of M1N2 (without mycorrhizae + 150 kg ha⁻¹ NPK fertilizer), while the lowest number of leaves was observed in the
M1N3 treatment (without mycorrhizae + 300 kg ha\(^{-1}\) NPK fertilizer). The difference in nutrient content contained in the soil and the dose of NPK fertilizer can affect the nitrogen content and absorption of the plant so that the formation of the number of leaves is different. In addition to the availability of nutrients, the water supply is one of the keys to plant leaf growth. If the water supply is sufficient, the leaves will carry out photosynthesis, resulting in increased leaf growth and an increased number of leaves. This is in accordance with the statement [20], stating that sufficient water supply leads to the opening of the stomata and increases CO2 uptake for photosynthesis, resulting in increased growth and number of leaves. [18] also state that the lack of water in plants will affect leaf formation, leaf area, and the number of leaves.

![Soybean plant height on peat soil with various treatments](image1.png)

**Figure 1.** Soybean plant height on peat soil with various treatments

![Number of leaves of the soybean plants on peat soil with various treatments](image2.png)

**Figure 2.** Number of leaves of the soybean plants on peat soil with various treatments

### 3.2.3 Shoot and root fresh weight

Plant growth by measuring fresh weight is one of the efforts or actions taken to determine the nutrient content present with plant growth. Figure 4.3 is the yield of fresh canopy and roots of soybean plants during the planting period 45 days after planting. The highest fresh weight of the roots was in M2N3 treatment which was treated by giving mycorrhizal and dose of 300 kg ha\(^{-1}\) NPK / ha fertilizer which was equal to 3.11 grams, while the lowest fresh weight of roots was found in M1N3 treatment which was treated without mycorrhiza and 300 kg ha\(^{-1}\) fertilizer. The highest shoot fresh weight was observed in the M1N2 treatment (without mycorrhizae + 150 kg ha\(^{-1}\) NPK fertilizer), which was 22.22 grams, while the lowest shoot fresh weight was found in M2N2 treatment (mycorrhizae + 150 kg ha\(^{-1}\)), which was equal to 12.22 grams. The fresh weight of plants illustrates the content of photosynthates and water contained in plant tissues.

### 3.2.4 Shoot and root dry weight
The dry weight of plants is plant material after all the water in the tissue is removed [7]. Dry weight is largely determined by the results of plant photosynthesis. The production of dry weight is strongly influenced by several factors such as nutrient absorption, sunlight, and the collection of carbon dioxide and water, all of which are determinants of photosynthesis. According to [19], the most influential nutrient to plant dry weight levels is P.

Figure 3. Shoot and root fresh weight of soybean plants on peat soil with various treatments

Figure 4. Shoot and root dry weight of soybean plants on peat soil with various treatments

Figure 4 presents the dry weight of shoots and roots of soybean plants with various types of treatment. The highest root dry weight was found in M2N2 treatment (with mycorrhizae + 300 kg ha$^{-1}$ NPK fertilizer), reaching 0.88 grams, while the lowest root dry weight was found in the M1N3 treatment (without mycorrhizae + 300 kg ha$^{-1}$ NPK fertilizer), reaching 0.62 grams. The highest dry weight of shoots was found in the treatment of M1N2 (with mycorrhizae + 150 kg ha$^{-1}$ NPK fertilizer), while the lowest shoot dry weight was found in the M1N1 treatment (without mycorrhizae + 0 kg ha$^{-1}$ NPK fertilizer), reaching 2.72 grams. The shoot dry weight was seen to be higher in the M1N2 treatment. Nevertheless, the higher net weight of the shoots was found in the M2N3 treatment. This is because, in the M2N3 treatment, the plants get input in the form of mycorrhizae and NPK fertilizer at a dose of 300 kg ha$^{-1}$, thus increasing the availability of P elements in the soil, leading to a larger opportunity for plants to absorb P elements to form a larger mass.

3.2.5 Root length
Figure 5 presents data on the length of the roots of soybean plants on day 45 after planting. The root length was measured by measuring the longest roots to the base of the roots of plants. In figure 5, the longest roots of soybean plants were found in M2N3 treatment (with mycorrhizae + 300 kg ha\(^{-1}\) NPK fertilizer), while the plants with the shortest roots were found in the M1N1 treatment (with mycorrhizae + 0 kg/ha NPK fertilizer).

![Graph showing root length of soybean plants on peat soil with various treatments](image)

Figure 5. Root length of soybean plants on peat soil with various treatments

Plant root length is one indicator of the plant's response to treatment. Nitrogen is an element that plays a major role in stimulating the vegetative growth of plants both in the shoots and roots [8]. Increasing the availability of nitrogen from the administration of NPK fertilizers with different doses makes the plant give a different root length growth response. In addition to N elements, P elements also play a role in stimulating the growth and development of roots. The application of mycorrhizal fungi and the addition of P elements through compound NPK fertilization will result in different effects on the growth and development of roots of soybean plants.

### 3.3 Effects of the application of mycorrhizae and doses of NPK fertilizer on P uptake of soybean plants

#### 3.3.1 P uptake in the roots of soybean plants

Table 6 shows the effect of various treatments on P uptake in the roots of soybean plants. Based on the analysis of variance, the application of mycorrhizae and doses of NPK fertilizers gave a significant effect on the absorption of phosphorus in the roots of soybean plants.

| Treatments | P uptake in the roots (gr/plant) |
|------------|---------------------------------|
| M1N1       | 0.194 b                         |
| M1N2       | 0.293 ab                        |
| M1N3       | 0.246 b                         |
| M2N1       | 0.222 b                         |
| M2N2       | 0.400 a                         |
| M2N3       | 0.325 ab                        |

Remarks: Values followed by the same letters in the same column are not significantly different according to DMRT at 5%.

M1N1= without mycorrhizae + 0 kg/ha NPK  
M2N1= with mycorrhizae + 0 kg/ha NPK  
M1N2= without mycorrhizae + 150 kg/ha NPK  
M2N2= with mycorrhizae + 150 kg/ha NPK  
M1N3= without mycorrhizae + 300 kg/ha NPK  
M2N3= with mycorrhizae + 300 kg/ha NPK

Based on table 6, the highest phosphorus uptake was observed in M2N2 treatment with a value of 0.400 gr/plant, while the lowest phosphorus conuptake was found in M1N1 treatment with a value of
0.194 gr/plant. Peat soil has a condition that does not support the availability of P elements, namely low soil pH. The use of mycorrhizae aimed to increase the supply of P nutrients for soybean plants. Besides, fertilization was also carried out as an effort to increase the availability of P nutrients in the soil. The application of mycorrhizae is not only effective for increasing the absorption of P nutrients in the soil but also effective for increasing other nutrients such as N, K, Ca, Mg, which are mobile in the soil [15].

3.3.2 P uptake in the shoots of soybean plants

Table 7 shows the effect of various treatments on the uptake of P element in soybean shoots. Based on the analysis of variance, the application of mycorrhizae and doses of NPK fertilizers had a significant effect on the uptake of phosphorus in the shoots of soybean plants.

Table 7. Effects of the application of mycorrhizae and doses of compound NPK fertilizer on the P uptake in the soybean shoots

| Treatments | P uptake in the shoots (gr/plant) |
|------------|----------------------------------|
| M1N1       | 1.15 b                            |
| M1N2       | 2.59 a                            |
| M1N3       | 2.70 a                            |
| M2N1       | 2.57 a                            |
| M2N2       | 3.17 a                            |
| M2N3       | 2.53 a                            |

Remarks: Values followed by the same letters in the same column are not significantly different according to DMRT at 5%.

M1N1= without mycorrhizae + 0 kg/ha NPK  M2N1= with mycorrhizae + 0 kg/ha NPK
M1N2= without mycorrhizae + 150 kg/ha NPK M2N2= with mycorrhizae + 150 kg/ha NPK
M1N3= without mycorrhizae +300 kg/ha NPK  M2N3= with mycorrhizae + 300 kg/ha NPK

Based on Table 7, the highest phosphorus uptake was found in M2N2 treatment with a value of 3.17 gr/plant, while the lowest phosphorus uptake was found in M1N1 treatment with a value of 1.15 gr/plant. From the analysis of variance, the application of mycorrhizae and doses of NPK fertilizer had a significant effect on P uptake in soybean shoots. P uptake in plant shoots affects plant height and number of leaves. This is in accordance with the results of [6], stating that mycorrhizal inoculation could increase plant height compared with plants that were not inoculated with mycorrhizae. In addition, the presence of mycorrhizal infections can increase nutrient absorption, especially P, so that the growth and development of organs such as leaves also increases.[4] explained that mycorrhizal fungi could increase the production of hormones such as auxin and cytokinin, which can function to increase cell wall elasticity and also prevent and slow down the aging process of roots. Therefore, mycorrhizae can provide an increase in nutrient uptake so that it can trigger the growth of the number of leaves of soybean plants.

4. Conclusion

The application of mycorrhizae in soybean cultivation on peatland was effective in increasing P uptake in plant roots and shoots and was able to increase the growth of soybean plants which were approached using observations of agronomic traits such as plant height, leaf number, root length, and plant dry weight. The higher the fertilizer dose given, the higher the phosphorus uptake and soybean growth. This is related to the increasing availability of nutrients for soybean plants. The dose of compound NPK fertilizer of 300 kg ha⁻¹ provided the best effect in the phosphorus uptake and the growth of soybean plants.

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