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Research Article

Growth and yield of rice from mycorrhizal enrichment seedlings on different soil water content

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ABSTRACT

The growth and yield of rice in limited soil water are expected to increase through the application of mycorrhizae due to the increasing root ability to absorb water and nutrients from the soil. The study aimed to determine the role of mycorrhizae on the growth and yield of rice plants in different soil water content. The study was conducted in Mempawah District, West Kalimantan, in February-June 2022. The experiment was arranged in a split-plot randomized complete block design with main plots of mycorrhizae treatment on seedlings (without and with mycorrhizae application), and subplots of soil water content (100%, 80%, 60%). The results showed that mycorrhizae could colonize 60-80% of roots and increase phosphorus absorption at up to 60% of soil water content. Application of mycorrhizae improved plant growth up to 80% of soil water content for the maximum number of a tiller, and 60% of soil water content for the leaf area. Mycorrhizae performed better to increase yield at up to 80% soil water content on the number of productive tillers and grain index of 1,000 seeds, and it performed better at a soil water content of 100% for grain weight per hill.

Keywords: microorganisms, plant resistance, rice production, root colonization

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INTRODUCTION

Increasing the growth and yield of rice is one of the essential aspects of Indonesian agriculture to date to cope with the increasing demand for domestic rice, both for public consumption and for the needs of the rice-based instant food industry. In 2018, domestic rice production was 29.57 million tons with a rice productivity level of 5.18 tons ha^{-1}, and it accounted for lower than domestic consumption of 38.1 million tons (Kementan, 2019; BPS, 2019). To fulfill the deficit, some amount of rice was imported from other countries.

West Kalimantan is one of the areas with a rice harvest area of 279,835.29 ha with lower productivity than the national productivity of 2.97 tons ha^{-1} (BPS, 2021). One of the causes of low rice productivity in West Kalimantan is a lack of water supply that inhibits rice growth and yield. Paddy fields in West Kalimantan are generally non-irrigated rainfed paddy fields with a harvested area of 218,468.40 ha, as well as dry or dry land with a harvested area of 183,853.13 ha (BPS, 2021). So that the strategy of increasing rice productivity as an effort to support food security requires a study of plant resistance to drought by applying cultivation technology through the application of mycorrhizae.

Regulation of soil water content in this study was carried out as a simulation for plant resistance to drought. According to Kusmana et al. (2018), the availability of sufficient soil water can support plant growth and development, namely influencing various metabolic reactions which impact increasing plant productivity. Gall et al. (2015) noted that in the limited level of soil water where plants experience drought stress, it disturbs the equilibrium of the solution in plant tissues which has an impact on the interaction of the cell wall and plasma membrane.

Rice requires soil water in a balanced condition during the growing period. Here, the application of mycorrhizae is aimed to expand the absorption rate of roots for water and nutrients. Basri (2018) mentioned that the mycorrhizae hyphae network assists to absorb soil water by expanding the absorption area of roots to water and nutrient; a smaller size of hyphae of mycorrhizae than roots penetrate more easily to smaller soil pores. According to Kiuk et al. (2022), the application of mycorrhizae support plants grows better. The study aimed to determine the role of mycorrhizae on the growth and yield of rice plants a different soil water content.

MATERIALS AND METHODS

The research was conducted in Mempawah District, West Kalimantan using a greenhouse. The time of research was from February to June 2022. The research materials were the Inpari 42 variety. Mycorrhizae fungi were applied in zeolite carriers with a spore density of ±170 spores per 100 g of zeolite (spore mix). Soil water content was managed by the application of rainwater according to treatment level.

The research used a split-plot randomized complete block design. The main plot was the mycorrhizae treatment (without and with mycorrhizae application), and the subplots were the treatment for regulating soil water content (100%, 80%, and 60%). The combination of 6 treatments was repeated 3 times using 5 plant samples as observation units.

An initial test was performed to identify the mycorrhiza. Spore identification was carried out (on zeolite carriers) at the Plant Diseases Laboratory, Universitas Tanjungpura. Spore density was ±170 spores per 100 g zeolite. The planting media in the form of alluvial soil was prepared after cleaning the soil and air-drying.

To determine the initial soil water content in the planting media, a soil analysis was carried out at the Chemical and Soil Fertility Laboratory of Universitas Tanjungpura. The soil had a 26% initial water content. To obtain 100% soil water content, about 58 mL of water was added per 100 g of soil. Dolomite lime was added at a dose of 26 g per polybag two weeks before transplanting. The polybag contained 14 kg soil at 100% soil water content. After the application of dolomite, the media inside the polybag was incubated for 2 weeks.

Transplant seedlings originated from two different growing media, without and with mycorrhizae application. The seeding aged 21 days. Before planting, the availability of mycorrhizae in root was evaluated at the Plant Disease Laboratory, Universitas Tanjungpura. Seedlings with and without mycorrhizae were planted separately in different main plots. Three seedlings were planted in each polybag.

From the time of seedling transplanting to 10 days after planting (DAP), the soil water content of all seedlings was maintained as much at 100%. After 10 DAP, adjustment of soil water content was carried out manually into 100%, 80%, and 60% by adding water on a daily basis. For technical simplification, we developed a formula as follows: a polybag weighed 14 kg had soil with a water content of 100%, a polybag weighed 11.2 kg had soil with a water content of 80%, and a polybag weighed 8.4 kg had soil with water content 60%. Every day in the morning, a sample of polybag with plants was weighed individually and the lost weight was recorded. For any deviation weight from the formula was then adjusted by adding water manually. For every reduction of 1 g of polybag, 1 mL of water was added. Here, the weight of the plant and fertilizers were excluded from the calculation of the formula.

Plant care was carried out by applying single NPK fertilizer, i.e., 200 kg urea ha^{-1} (1.25 g per polybag), 100 kg SP-36 ha^{-1} (0.63 g per polybag), 50 kg KCl ha^{-1} (0.31 g per polybag) followed a recommendation from BPTP (2019). Weeds on every planting media were controlled manually by uprooting. Rice grains were harvested when 90-95% of the panicles turned yellow.

Growth traits observations started after treatment. At 8 weeks after planting (WAP) or at the maximum vegetative phase, the number of tillers was evaluated by counting all the tillers that appear per hill. Leaf area evaluation used leaf area meter (Delta-T) single destructive sampling. The crop yield component was evaluated for the number of productive tillers (tiller with panicles), the weight of the dry-milled grain of 1,000 seeds, and the weight of the dry-milled grain per hill. At the maximum vegetative growth, root colonization by mycorrhizae was evaluated using 10 cut roots per plant. Plant phosphorus level was evaluated at a similar time of root colonization using three sample plants.

RESULTS AND DISCUSSION

Root colonization by mycorrhizae

Root colonization by mycorrhizae at 8 WAP for mycorrhizae-treated seedlings showed variation according to a soil water content of 100% (80%±0.67), 80% (60%±1.15), and 60% (80%±0.82) (Figure 1). On the other side, untreated mycorrhizae seedlings had no root colonization. Here, it means that colonization of mycorrhizae in rice seems stable across the soil water content. Figure 2 shows that mycorrhiza resides inside the root, with some hyphae extended outside the roots. It has been studied that mycorrhizae hyphae that colonize the roots function as root extensions to absorb water and nutrients (Simamora et al., 2015; Messa et al., 2020).

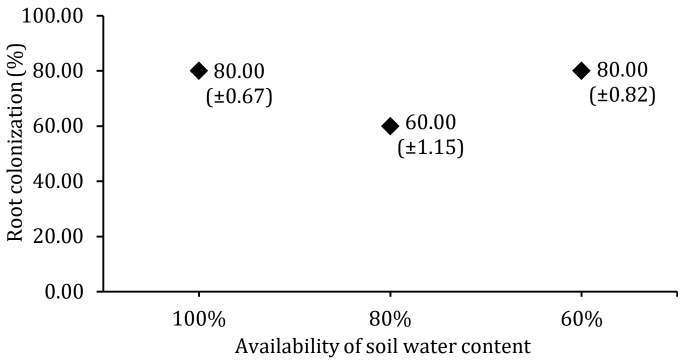

Figure 1. Percentage of rice root colonization by mycorrhizae in the maximum vegetative phase.

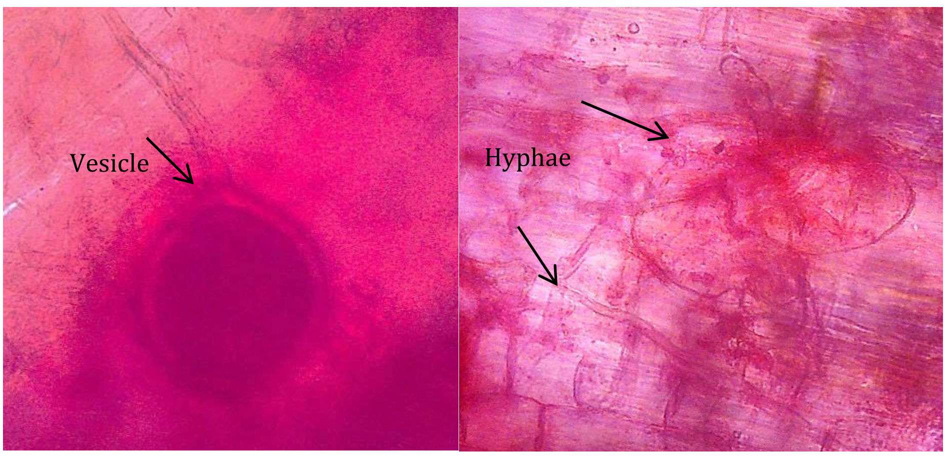

Figure 2. Cross-section of Mycorrhizal infected roots.

Phosphorus uptake

There was a different ability of rice to absorb phosphorus depending on the treatment of mycorrhizae (Figure 3). The highest phosphorus uptake of plants without mycorrhizae treatment was 0.083 g at a soil water content of 80%. In comparison, the lowest absorption of phosphorus nutrients for rice plants infected with mycorrhizae was 0.093 g at a soil water content of 80%. It shows that phosphorus uptake from plants without mycorrhizae is still below the lowest phosphorus absorption from plants infected with mycorrhizae. This proves that mycorrhiza is essential to uptake phosphorus nutrients in rice plants. The low uptake of phosphorus nutrients from rice plants infected with mycorrhizae at a soil water content of 80% could be caused by root colonization in this treatment which was still lower than at soil water content of 60% and 100% (Figure 1). Thus, maximum colonization is important to increase phosphorus uptake in rice plants.

Plant absorption ability on phosphorus of different soil moisture content in the absence of mycorrhiza followed the equation $Y = -0.5875x^2 + 0.9275x - 0.283$ ($R^2 = 1$) (Figure 3a). In such cases, the highest plant ability to absorb phosphorus nutrients at a water content of 80% was 0.083 g. In the presence of mycorrhizae, the ability of phosphorus uptake followed the equation $Y = 0.7375x^2 - 1.2225x + 0.599$ ($R^2 = 1$). It seems that the plant's ability to absorb nutrients was the highest phosphorus in 60% soil water content, i.e., 0.131 g (Figure 3b). These facts indicate that soil water status could be an important condition for mycorrhizae in relation to phosphorus uptake.

According to Mutiarahma et al. (2020), the increase in the ability of plants to absorb phosphorus nutrients by administering mycorrhizae is due to the external mycorrhizal hyphae having the ability to produce phosphatase enzymes that help to extract phosphorus from the soil. Furthermore, Golubkina et al. (2020) noted the additional ability of mycorrhizae to increase the bioavailability of the phosphorus nutrients in the soil.

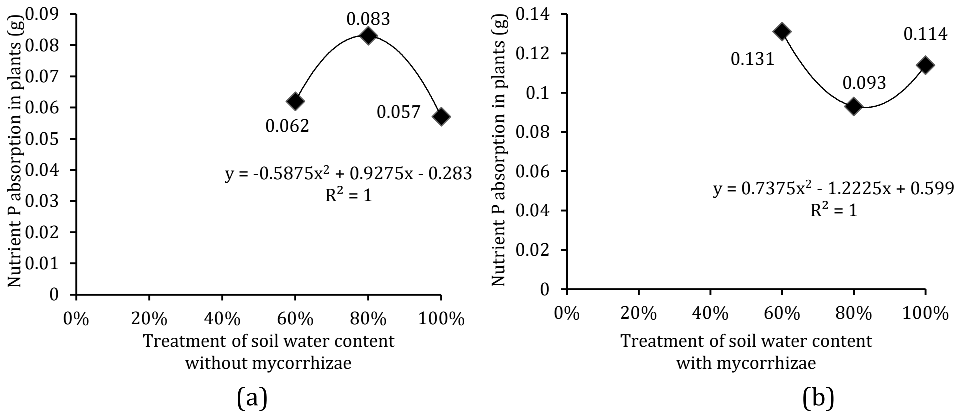

Figure 3. Uptake of phosphorus nutrients in rice plants in the maximum vegetative phase with the regulation of soil water content without mycorrhizae (a) and with mycorrhizae (b).

Tiller number

The tiller number was significantly influenced by mycorrhizae treatment and soil water content (Table 1). In the absence of mycorrhizae, soil water content did not affect tiller number, it ranged from 9-10 tillers. On the other side, tillering was affected by soil water content for seedlings treated with mycorrhizae. The number of tillers increased by increasing soil water content from 60% to 80 and 100% followed by the provision of mycorrhizae. Yoshida and Hayakawa (1970) mentioned that rice tillering is strongly affected by the status of NPK in the plant, tillering in rice becomes zero at about 2% nitrogen, 0.03% phosphorus, and 0.5% potassium in the leaf blade but very active at the

N, P, and K status of > 2%, 0.2% and 1.5%, respectively. High P uptake in mycorrhizae plants (Figure 3) followed by adequate soil water could finally be followed by increasing assimilates for the formation of tillers. Susilawati et al. (2012) pointed out that phosphorus altogether with nitrogen plays an important role in the tiller number of rice in many varieties.

The role of water is important in rice. Water shortage in soil media affects the root's ability to absorb nutrients in the soil as well as disturbs nutrient transportation in plant tissue (Herdiyanti et al., 2021). Continuous water shortage affects photosynthesis performance and finally inhibits plant growth and development (Sumadji & Purasari, 2018). According to Cavagnaro et al. (2021), rice plants with roots colonized by mycorrhizae are generally able to provide a positive response in supporting plant growth to support the formation of maximum tillers.

Table 1. Maximum number of tillers and leaf area of rice in mycorrhizae treatments and soil water content at 8 WAP.

Mycorrhizae	Soil water content	Tiller number	Leaf area (cm^2)
Without mycorrhizae	100%	9b	45.98ab
	80%	10b	53.76ab
	60%	9b	37.56b
Mycorrhizae applications	100%	19a	60.61a
	80%	17a	42.03ab
	60%	11b	48.57ab
HSD (5%)		3.85	19.83

Note: Values in a column followed by the same letters are not significantly different based on the HSD test at the 5% level.

Leaf area

The leaf area of rice plants is significantly influenced by mycorrhizae treatment and regulation of soil water content (Table 1). The average leaf area on the HSD test results obtained the highest value on the interaction of mycorrhizae and 100% soil water content which was significantly wider by 7.99% compared to the leaf area on the interaction without mycorrhizae and 60% soil water content, but there was no significant difference to other treatments. Table 1 shows that the combination of 100% soil water content and mycorrhizae application produced the widest leaf area in rice. Plant with wider leaf area generally has a higher ability in photosynthesis. Higher photosynthesis also stimulates plants to absorb higher water and nutrients from the soil. The process of absorption of nutrients and water by plant roots can be influenced by the formation of root extensions due to mycorrhizae colonization with its ability to expand the root absorption area down to the smallest soil particles (Wahyuningratri et al., 2017).

In low soil water availability, the plant has a lower number of stomata means a lower transpiration rate (Prabawati et al., 2017; Suminarti et al., 2020). In the present experiment, the leaf blade size of rice decreased by decreasing soil water content (Table 1). Nevertheless, a plant treated with mycorrhizae growing with a low soil water content of 60% nearly had a leaf area equal to the plant without mycorrhizae treatment grown with 80% water content. It means that decreasing in lower soil water could be compensated by the application of mycorrhizae. Quiroga et al. (2017) revealed that arbuscular mycorrhizal application improves maize growth under drought stress. It is interesting in the future, to evaluate the role of mycorrhizae on drought tolerance in rice.

Productive tiller number, index 1,000 grain, and weight per hill

The number of productive tillers was significantly influenced by mycorrhizae treatment and regulation of soil water content (Table 2). The results of the HSD test showed that the interaction of mycorrhizae and 100% soil water content did not show a significant difference with the interaction of mycorrhizae and 80% soil water content, but significantly more by 10.14% compared to the mycorrhizae treatment and 60% soil water content, and significantly more a lot of 14.49% compared to interactions without mycorrhizae and soil water content of 100%, 80% and 60%. The high or low number of productive tillers formed in the results of this study can be caused by the large number of maximum tillers in a plant. Productive tiller number highly correlates with tillering ability (Susilo et al., 2015; Arinta & Lubis, 2018). According to Arinta and Lubis (2018) that the positive relationship that occurs between plants with a higher maximum number of tillers can also produce higher productive tillers.

Table 2. Number of productive tillers, weight of 1,000 seeds, and grain weight per hill in mycorrhizae treatment and soil water content.

Mycorrhizae	Soil water content	Productive tillers	Weight of 1,000 seeds (g)	Grain weight per hill (g)
Without mycorrhizae	100%	8b	19.03c	21.99c
	80%	8b	19.27c	18.92c
	60%	8b	19.43c	21.93c
Mycorrhizae applications	100%	18a	28.93a	106.20a
	80%	16a	25.00ab	72.90b
	60%	11b	20.47bc	32.67c
HSD (5%)		4.12	5.53	20.90

Note: Values in a column followed by the same letters are not significantly different based on the HSD test at the 5% level.

The grain weight of 1,000 seeds was significantly influenced by mycorrhizae treatment and regulation of soil water content (Table 2). Soil water content did not affect grain index in treatment without mycorrhizae, contrary to treatment with mycorrhizae. All mycorrhiza-treated plants produced higher seed indexes than those of non-treated ones, irrespective of soil water content.

Grain weight per hill was significantly influenced by mycorrhizae treatment and regulation of soil water content (Table 2). Soil water content did not significantly affect gain weight per hill in non-mycorrhizal plants, contrary to mycorrhizal plants. Mycorrhizal plants had higher grain weight per hill as compared to non-mycorrhizal plants, except mycorrhizal plants grown with 60% soil water content. In general, mycorrhizal plants are significantly heavier by 30.67%, 31.78%, and 30.69% than the treatment without mycorrhizae grown at a soil water content of 100%, 80%, and 60%, respectively. Here, different grain weight per hill among treatments is likely affected by grain index 1000 seed and number of productive tillers (Table 2). Mycorrhizae application followed by 100% soil water content produced the highest grain weight per hill, i.e., 106.20 g. According to Maisura et al. (2017) that the limited availability of water to plants during the generative phase can result in grain yields being formed and causing higher empty grains in each panicle as a result of incomplete seed filling.

The formation of grain index of 1,000 seeds and grain weight of hill in the present study is likely determined by the absorption of the nutrient phosphorus which was higher in mycorrhizae rice plants compared to plants without mycorrhizae. According to Jeong et al. (2017) increased phosphorus in plants contributes to increasing rice yields. Furthermore, Rehim et al. (2014) stated that phosphorus application significantly increases the number of productive tillers, the weight of 1000 seeds which in turn increases the yield of rice plants. In addition, the availability of sufficient water for plants also supports plant metabolic processes which ultimately determine the amount of photosynthate that plants can produce and store for seed formation and filling.

CONCLUSIONS

Mycorrhizae-enriched seedlings improved rice growth and yield. In limited water availability of 80% soil water content, application of mycorrhizae simulated the number of tillers and at 60% soil water content still able to maintain the leaf area of rice. Mycorrhizae have a role in increasing rice yields which are better up to 80% soil water content based on the number of productive tillers and grain weight of 1,000 seeds, as well as the better soil water content of 100% on grain weight per hill. Present research implies that the application of mycorrhizae in seedling of rice is likely improve plant growth and yield in limited soil water content. It is interesting in the future to study the effect of mycorrhizae on various rice genotypes against drought stress.

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