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Effects of Mycorrhiza Biofertilizer and Combined Zn-S Fertilization on Rice Performance in Sole and Cover Crop Intercropping Systems

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ABSTRACT

This study aimed to determine the effects of intercropping with cover crops, mycorrhiza biofertilizer, and combined Zn-S fertilization on the growth of two rice types. Three pot experiments, designed using a completely randomized design (CRD) with four replications, were conducted simultaneously from September to November, 2025. Experiment #1 tested the effects of mycorrhiza biofertilizer and Zn–S fertilization in a factorial arrangement on monocropped rice, including two rice types (black and white). Experiment #2 tested the same factors on monocropped cover crops (peanut and peppermint). Experiment #3 tested the same factors in rice–cover crop intercropping, with each rice type intercropped separately with each cover crop species. The results showed that mycorrhiza biofertilizer and Zn-S fertilization significantly increased rice and cover crop biomass, both in monocrop and intercropping systems, and the land equivalent ratio (LER) of the intercropping. However, there were significant interaction effects, and the interaction patterns revealed synergistic effects of mycorrhiza biofertilizer and Zn-S fertilization in increasing biomass of the monocrops, as well as LER of the intercropping, indicating the critical importance of mycorrhiza biofertilizer and Zn-S fertilization of upland rice or cover crops grown following flooded rice, which warrants further investigations.

1. INTRODUCTION

In Indonesia, rice is the most important staple food because most of the Indonesian population eats rice, and often without adequate side dishes, even though the nutritional intake is not necessarily adequate. In addition to white rice, which is generally consumed by the population, there is also red rice and black rice. This colored rice (red or black) can be used not only as a staple food, but also as a functional food because of its high health value, especially its anthocyanin content, which is a compound that functions as an antioxidant [1]. In addition to the antioxidant content that is healthy for the human body, one of the nutrients whose intake must be adequate, especially for toddlers and children, is Zinc, because Zinc deficiency can cause stunted growth in toddlers [2, 3].

Zinc levels are also related to the type of rice, where colored rice, such as black rice, contains higher levels of Zinc compared to white rice [4]. However, children generally prefer white rice to black rice. Therefore, ideally, it is very important to create rice with high nutritional content, such as Zinc and iron, especially in white rice that is preferred by children and most people. In addition, increasing Zn and Fe contents of red and black rice can further increase their health values. However, rice is generally planted conventionally with a flooded system, and rice fields that are always planted with flooded rice result in a decrease in Zn availability [5, 6]. Zn deficiency causes stunted rice growth, reduces the number of tillers, and increases grain sterility, thereby increasing the number of unfilled grains and significantly reducing grain yields [7, 8]. These mean that deficiency in Zn availability will hamper any effort to increase rice productivity without Zn fertilization due to Zn's essential roles in growth and yield formation of rice plants.

Data from the Indonesian Central Bureau of Statistics shows that rice productivity is leveling off, with productivity ranging from 5.11 t/ha in 2019 to only a gradual increase to 5.29 t/ha in 2024, with total production decreasing from 54,604,033 tons in 2019 to 53,142,727 tons in 2024, primarily due to a decrease in total harvested area [9]. Since the majority of the people in Indonesia consume rice as a staple food, rice production must be gradually increased. To be able to increase rice production under decreasing harvested areas will require various efforts to increase productivity.

One way to increase rice productivity from the upland system is by intercropping rice with legumes, such as peanuts [10] or soybeans [11]. In red rice intercropped with mungbean and supplied with mycorrhiza biofertilizer, although the NPK fertilizer dose was reduced to 60% of the recommended dose, grain yield was still higher than that without intercropping and without biofertilizer application [12]. Unfortunately, when compared with flooded rice cultivation systems, dry rice cultivation systems and aerobic irrigated rice systems are generally very full of weed competition, which has the potential to reduce rice productivity by up to 30-80% [13].

However, planting cover crops between rice rows has been reported to reduce weed growth [14]. Cover cropping using peanuts or pinto peanuts can also increase growth and yield of upland rice [15], and planting rice together with legume crops such as peanuts can facilitate N transfer from the peanut rhizosphere to the rice plants [16]. From long-term research on crop rotation systems, it was reported that in rotation systems that include legume crops such as peanuts (Summer peanuts), levels of available Zn were higher than in rotation systems that do not include legume crops [17]. In an intercropping system of maize with peanut, it was found that N uptake by peanut increased 2.5 times in the intercropping system compared to monocropped peanut, but Zn levels in intercropped maize tended to be lower than in monocropped maize [18]. If symbiosis with arbuscular mycorrhizal fungi (AMF) is involved in the legume-cereal intercropping system, nutrient transfer between crop species can increase, such as the transfer of N from legumes to cereals [19].

This study aimed to determine the effect of the application of mycorrhiza biofertilizer and Zn-S fertilization on the growth of rice and cover crops, both planted in sole and in intercropping systems, and to examine those effects on the land equivalent ratio (LER) of the intercropping systems.

2. MATERIALS AND METHODS

This pot experiment was conducted on a paddy rice land in Kebon Ayu rice field (West Lombok, Indonesia), using the soil taken from the rice land previously used to grow flooded rice (with a long history of growing flooded rice), and after planting, the pots were placed in open land between the raised beds of aerobic irrigated rice plants. There were three sets of pot experiments conducted simultaneously from September to November, 2025, which were arranged according to CRD (Completely Randomized Design), all with four replications. Experiment #1 was a monocrop rice experiment, examining three treatment factors: rice types (P1: black rice (Ph), P2: white rice (Pp)), application of mycorrhiza biofertilizer (M0: without, M1: with mycorrhiza), and Zn-S fertilization (Z0: without, Z1: with Zn-S fertilization). Experiment #2 was a monocrop cover-crop experiment, examining three treatment factors: cover crop species (C1: peanut; C2: peppermint), as well as mycorrhiza and Zn-S treatment factors as in Experiment #1. Experiment #3 was an intercropped rice experiment, examining four treatment factors: two rice types (back and white rice), two cover crop species as intercrops (peanut and peppermint), as well as mycorrhiza and Zn-S treatment factors as in Experiment #1. To calculate the LER values of intercropping, the biomass data of the monocrop plants in Experiment #1 and Experiment #2 were used as the denominator in calculating the partial LER of each crop and summed to obtain the total LER for each experimental unit in Experiment #3.

The buckets of 4.5-liter capacity used for the pot experiment were filled with 4.5 kg of sifted air-dried paddy rice soil, after holes were made on the left and right sides, 1 cm above the inside-bottom of the pot for sub-irrigation and drainage. Mycorrhiza biofertilizer was applied to the planting holes during planting at a dose of 5 grams as recommended in the product (300 propagules per gram). For the rice intercropping system with cover crops, planting holes were made 5 cm apart around the midpoint of the pot diameter. At 10 days after seeding (DAS), thinning was carried out by leaving two plants per planting hole, followed by the first fertilization. For the treatment Z1 (with Zn-S fertilization) the soil was fertilized with Phonska Plus (15% N, 15% P_2O_5, 15% K_2O, 9% S, 2000 ppm Zn) at a dose of 200 kg/ha (or 1 g/pot) for all crops, and follow-up fertilization was only for rice plants with Phonska Plus (1 g/pot) at the age of 40 DAS. For the treatment Z0 (without Zn-S fertilization), Phonska Plus was replaced with "Mutiara" NPK (16% N, 16% P_2O_5, 16% K_2O) fertilizer by adjusting the fertilizer dose to 187.5 kg/ha, applied on the same application day as the Z1 treatment. For the intercropped plants, fertilizer was dibbled in the opposite position of each plant. Irrigation was carried out through sub-irrigation holes once a week until the age of 35 DAS, then increased to once every 4 days until the vegetative harvest at the age of 70 DAS, which was at the booting stage of the white rice ("Situ Patenggang" variety) and the late vegetative stage of the black rice ("Inpari Unram-1" variety).

Observations were made on the dry weight of the aboveground plant parts. Data were analyzed using ANOVA and Tukey's HSD at a 5% significance level, using CoStat for Windows. The LER value was calculated by summing the partial LERs of each intercropped crop species.

3. RESULTS AND DISCUSSION

3.1 The effect of mycorrhiza biofertilizer and zinc on two rice varieties planted in monocrop

The results of the data analysis of Experiment #1 using ANOVA (Table 1) show that rice types (white vs. black) had no significant difference in their shoot dry weight (biomass) ($p > 0.05$), while the application of mycorrhiza biofertilizer ($p < 0.001$) and Zn-S significantly ($p < 0.001$) increased the biomass of rice plants (Figure 1). However, there was a significant Rice*Myc two-way interaction ($p = 0.0005$) and a three-way Rice*Myc*Zn interaction ($p = 0.0054$) on the rice plant biomass weight. Based on the interaction pattern, Figure 2 shows that the application of mycorrhiza biofertilizer more significantly increased the biomass of white rice (67.3%) compared to black rice (31.2%), which means that the white rice was more responsive to mycorrhiza biofertilizer compared to the black rice.

Table 1. Summary of ANOVA results of the effect of rice type, mycorrhiza, and Zn-S fertilizer on rice biomass

Source of Variance	F-Calc.	P-Value
Main Effects		
Rice types	2.80	0.1070
Mycorrhiza biofertilizer (Myc)	201.30	**0.0001**
Zn-S (Zn)	81.75	**0.0001**
Interaction Effects		
Rice*Myc	15.92	**0.0005**
Rice*Zn	2.29	0.1430
Myc*Zn	0.40	0.5347
Rice*Myc*Zn	9.37	**0.0054**

These two types of rice are different in terms of their development. This white rice was developed as an upland rice variety, and it is one of the superior national upland rice varieties in Indonesia. The black rice used in this study was developed as an irrigated rice variety. Huang et al. [20]

concluded that differences in AMF symbioses among rice varieties might result from their adaptation to different soil conditions. Surveys in Lombok (Indonesia) also reported that AMF colonization levels and spore counts were higher on rice grown on soil with less flooded conditions, and they were highest in upland rice [21, 22]. Diedhiou et al. [23] also reported that among various rice varieties tested, the best responses to AMF inoculation were shown by upland rice varieties, which is in line with the finding in this study, that the white rice (an upland rice variety) was more responsive to mycorrhiza biofertilizer than the black rice (an irrigated rice variety).

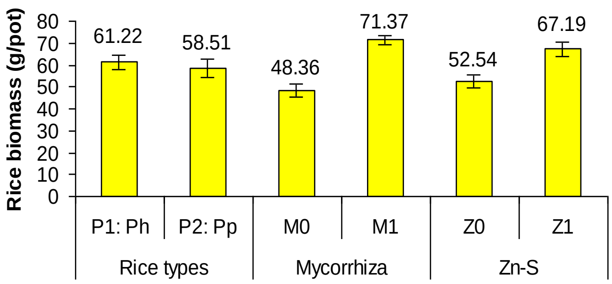


Figure 1. Average biomass of plants/pot) for each treatment factor (main effects)

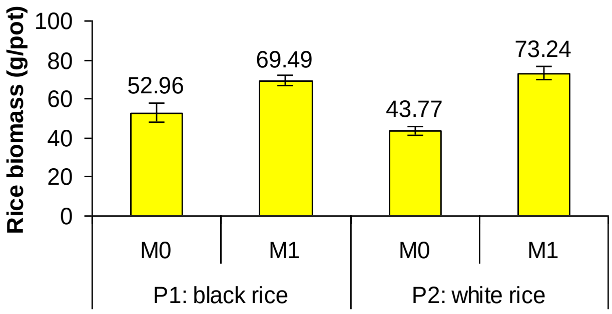


Figure 2. Effect of the interaction between rice type and mycorrhiza on monocrop rice biomass

The pattern of three-factor interaction in Figure 3 also shows that white rice was more responsive to Zn-S application compared to black rice. In addition, white rice clearly shows a synergistic effect between mycorrhiza biofertilizer and Zn-S fertilization, but the synergistic effect was not shown by the black rice (Figure 3). These also indicated the different responses of these rice varieties to mycorrhiza biofertilizer and/or to Zn-S fertilization.

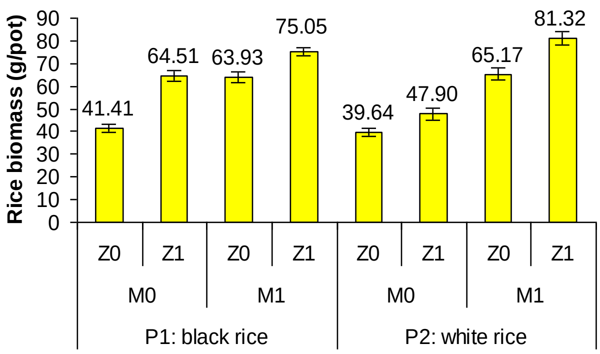


Figure 3. The effect of the interaction of three factors, between rice type, mycorrhiza, and zinc fertilizer, on the biomass of monocrop rice (g/pot)

It can also be calculated from Figure 3, that under no Zn-S fertilization, application of mycorrhiza biofertilizer increased biomass of the white rice by 64.4%, while for the black rice it was only 54.4%, which indicates the higher mycorrhiza responsiveness of the white rice (upland rice variety) than the black rice, which is an irrigated rice variety [23]. This could be the factor causing higher biomass weight of the white rice (81.32 g/pot) under application of mycorrhiza biofertilizer and Zn-S fertilization when compared to that of the black rice (75.05 g/pot) (Figure 3).

In addition to the positive effects of mycorrhiza biofertilizer application, Zn-S fertilization also significantly increased the weight of rice plant biomass (Figure 3). This shows the significant role of Zn-S in plants planted after flooded rice systems, the soil of which was used for pot experiments in this study. Islam et al. [24] also reported a significant effect of Zinc fertilizer on the yield and yield components of various rice varieties in Bangladesh. However, Kandil et al. [25] reported an interaction effect between rice varieties and Zinc fertilizer, which indicated different responses between rice varieties to Zinc fertilizer doses. Zinc uptake was also reported to vary between rice varieties [7]. In this study, the experimental results showed an interaction among rice types, mycorrhiza biofertilizer, and Zn-S fertilization, which showed that the response to Zn-S fertilization depended on the types or varieties of rice (different between black rice and white rice) and the presence or absence of mycorrhiza biofertilizer (Figure 3).

3.2 Effect of mycorrhiza and Zn-S on monocrop peanut and peppermint as cover crops

The results of the data analysis of Experiment #2 using ANOVA (Table 2) show that there were significant biomass differences between the two types of cover crops, and the significant main effects of both mycorrhiza biofertilizer and Zn-S fertilization in increasing cover crop biomass weight. In addition, there were significant interaction effects between types of cover crops and mycorrhiza (CC*Myc), as well as between mycorrhiza and Zn-S fertilization (Myc*Zn). Based on the patterns of the interaction effects, both peanut and peppermint as cover crops were very responsive to the application of mycorrhiza biofertilizer, but peanut seems to be more responsive than peppermint, where the biomass weight of peanut plants was 31.2% higher ($p < 0.01$) and that of peppermint was 22.8% higher ($p < 0.01$) under the application of mycorrhiza biofertilizer compared to without mycorrhiza biofertilizer (Figure 4).

Table 2. Summary of ANOVA results of the effect of rice type, mycorrhiza, and Zn-S fertilizer on cover crop biomass

Source of Variance	F-Calc.	P-Value
Main Effects		
Cover Crops (CC)	104.48	**0.0001**
Mycorrhiza biofertilizer (Myc)	41.16	**0.0001**
Zn-S (Zn)	37.04	**0.0001**
Interaction Effects		
CC*Myc	4.28	**0.0495**
CC*Zn	0.17	0.6819
Myc*Zn	4.81	**0.0383**
CC*Myc*Zn	0.13	0.7214

In addition, these two species of cover crops also showed a synergistic effect of mycorrhiza biofertilizer and Zn-S fertilization on their biomass weight, in which Zn-S application more significantly increased the biomass of cover crops (32.6%) if the crops were supplied with mycorrhiza biofertilizer compared to only 18.4% in the cover crops that were not supplied with mycorrhiza biofertilizer (Figure 5).

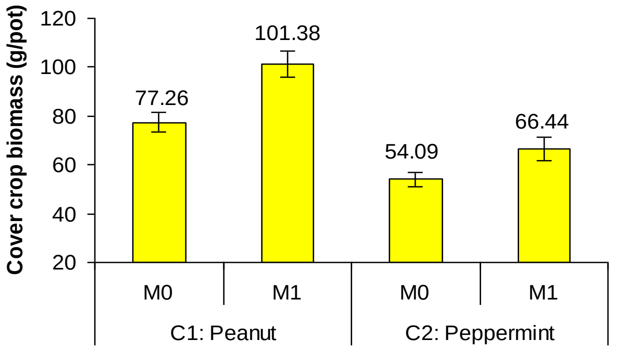


Figure 4. The effect of the interaction between cover crop and mycorrhiza types on the biomass of monocrop cover crops

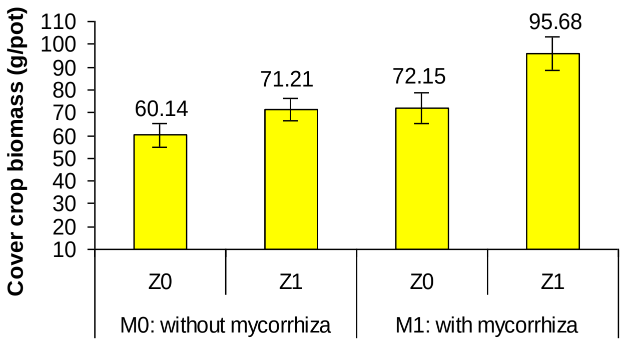


Figure 5. The effect of the interaction between mycorrhiza biofertilizer and zinc on the biomass of monocrop cover crops

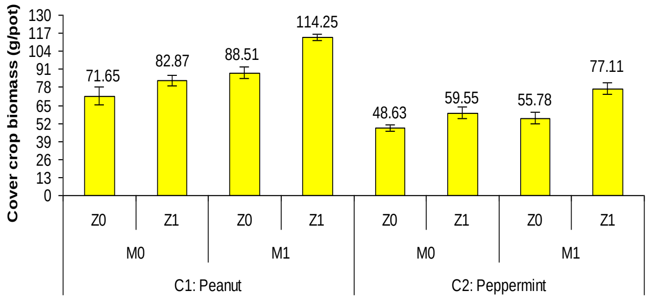


Figure 6. Effect of interaction between cover crop type, mycorrhiza biofertilizer, and zinc on the biomass of monocrop cover crops

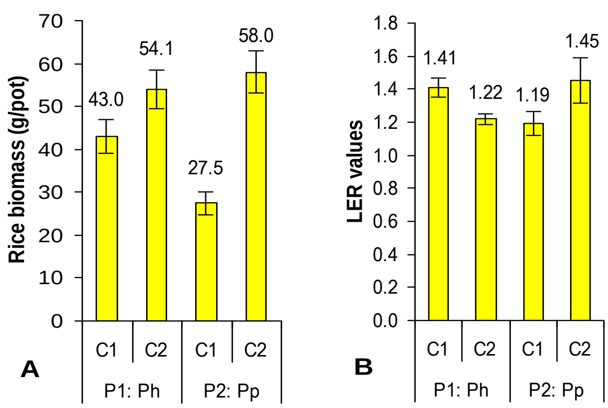
In more detail, although the three-way interaction effect was not significant (Table 2), it can also be seen from Figure 6 that this synergistic effect occurred in both types of cover crops, i.e., both in peanut and peppermint plants. Although the average dry weight (mean values of M0 and M1 calculated from Figure 4) of peppermint (60.27 g/pot) was lower than that of peanut (89.32 g/pot), the synergistic effect of mycorrhiza biofertilizer and Zn-S fertilization was stronger in peppermint than in peanut. It can be calculated from Figure 6 that under no application of mycorrhiza biofertilizer, Zn-S fertilization increased peppermint dry weight only by 22.5%, but with the application of mycorrhiza biofertilizer, Zn-S fertilization increased peppermint dry weight by 38.2%. In peanut, without mycorrhiza biofertilizer, Zn-S fertilization only increased peanut dry weight by 15.7%, but with mycorrhiza biofertilizer, Zn-S fertilization increased peanut dry weight by 29.1%. This means that peanut was more responsive to the application of mycorrhiza biofertilizer, while peppermint was more responsive to Zn-S fertilization. Peanut planted following irrigated rice in intercropping with black rice under aerobic irrigation systems was also very responsive to mycorrhiza biofertilizer [26]. Mycorrhizal fungi were also reported to significantly increase root colonization, growth, and yield of mint and increase N, P, and K uptake in menthol mint plants [27].

One of the most important benefits of establishing AM (arbuscular mycorrhizal) symbiosis between host plants and AMF is improvement of nutrient uptake, especially immobile nutrients such as phosphorus, as well as improvement in abiotic stress tolerance, including low nutrient and water stresses [28-30]. Availability of Zinc is commonly very low in soil, and precipitation of both P and Zn can occur through the formation of zinc phosphate, making them unavailable for plant root uptake [31]. However, AMF inoculation was reported to improve uptake of both P and Zn by rice plants [32-34]. Due to the essential roles of Zn in increasing chlorophyll contents and photosynthetic rates in rice plants [35], and Zn uptake can be improved by AMF inoculation [32, 34], it is highly possible that application of mycorrhiza biofertilizer and Zn-S fertilization can increase the growth of rice plants, as it can be seen in Figure 3.

3.3 Effect of mycorrhiza and Zn-S on rice intercropped with peanut or peppermint as cover crops and their land equivalent ratio

The ANOVA results of the rice and cover crop biomass weight from Experiment #3, as well as the LER values for both types of crops, are summarized in Table 3. It is clear that the significant effect of Zn-S fertilization was the most dominant among the four treatment factors, in which Zn-S showed a significant effect on biomass weight of both rice and cover crops in intercropping, as well as their LER values (Table 3).

However, there were significant interaction effects between the treatment factors, particularly between rice type and mycorrhiza biofertilizer (Ric*Myc), as well as between other treatment factors. Since there were significant interaction effects between various combinations of the treatment factors, i.e., two-way, three-way, and four-way interactions (Table 3), the significant or non-significant effects of the treatment factors (main effects) cannot be considered as conclusive.



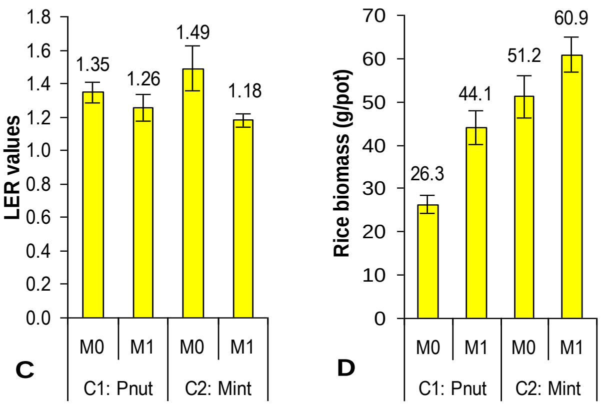


Figure 7. The effect of the interaction of two factors: (A) Rice type and intercropping on rice biomass; (B) Rice type and intercropping on LER value; (C) Intercropping and mycorrhiza on LER value; (D) Intercropping and mycorrhiza on rice biomass

Based on the pattern of interaction effects between the types of rice and intercropping with cover crops (Ric*Int), it can be seen from Figure 7(A) that the dry weight or biomass of rice plants differs between black rice (Ph) and white rice (Pp) depending on the type of cover crop. Rice plants produce higher biomass when planted with peppermint compared to peanuts, indicating higher competition of peanut than peppermint, and white rice experienced heavier competition with peanut compared to black rice, which results in the biomass of white rice planted with peanut being the lowest (27.5 g/pot), while with peppermint, the dry weight was the highest (58.0 g/pot). This is thought to be the condition that causes the highest LER value of white rice (1.45) when planted with peppermint and the lowest (1.19) when planted with peanuts (Figure 7(B)).

Similarly, the highest LER (1.49) was found in rice planted with peppermint without mycorrhiza biofertilizer (Figure 7(C)), even though the highest dry weight of rice plants was achieved when planted with peppermint and supplied with mycorrhiza biofertilizer (Figure 7(D)). The contrast between the highest dry weight (Figure 7(D)) and LER (Figure 7(C)) is thought to occur because the dry weight of the monocrop plants was very low in the monocrop C2M0 treatment, i.e. without application of mycorrhiza biofertilizer (Figure 4), so that the LER increased, becoming higher in the C2M0 than in the other treatments (Figure 7(C)).

Among the two-way interactions, the interaction between rice type and mycorrhiza showed a significant influence on all three observed variables of the rice plants intercropped with cover crops (Table 3). The effect of this interaction shows that the highest LER value was in the P2M0 treatment combination (Figure 8(A)) and in M0Z1 (Figure 8(B)), accompanied by the highest average value of intercropped cover crop biomass, which was also in P2M0 (Figure 8(C)), but conversely, the lowest rice plant biomass was in P2M0 and the highest in P1M1 (Figure 8(D)). This is thought to occur because the biomass of monocrop rice plants was also the lowest in the P2M0 treatment combination (Figure 2), and the biomass of monocrop C2 (peppermint) was also the lowest in the C2M0 treatment combination (Figure 4), thus increasing the LER value, because monocrop biomass is the divisor in calculating the LER value. The lowest biomass weight of the plants in P2M0 (white rice) and C2M0 (peppermint) is thought to be due to without application of mycorrhiza biofertilizer because both rice types, especially white rice [23] and peppermint [27], are very responsive to mycorrhizal inoculation.

Table 3. Summary of ANOVA results of the effect of rice type, intercropping with cover crops, mycorrhiza biofertilizer, and Zn-S fertilizer on rice biomass, cover crops, and land equivalent ratio (LER) values of the intercropping

Source of Variance	Rice Plant Biomass		Cover Crop Biomass		Land Equivalent Ratio (LER)	
	F-Calc.	P-Value	F-Calc.	P-Value	F-Calc.	P-Value
Main Effects						
Rice types (Ric)	9.86	**0.003**	1.80	0.186	0.05	0.827
Intercropping (Int)	127.39	**0.000**	436.29	**0.000**	0.62	0.435
Mycorrhiza (Myc)	55.53	**0.000**	0.16	0.694	20.58	**0.000**
Zn-S (Zn)	102.24	**0.000**	38.74	**0.000**	17.48	**0.000**
Interaction Effects						
Ric*Int	27.99	**0.000**	2.39	0.129	26.34	**0.000**
Ric * Myc	9.22	**0.004**	36.76	**0.000**	56.09	**0.000**
Int * Myc	4.78	**0.034**	2.25	0.140	6.21	**0.016**
Ric*Int*Myc	8.32	**0.006**	0.02	0.887	0.01	0.949
Ric * Zn	0.16	0.691	28.99	**0.000**	24.76	**0.000**
Int * Zn	57.89	**0.000**	0.58	0.452	30.11	**0.000**
Ric*Int*Zn	0.09	0.771	0.62	0.434	1.51	0.225
Myc * Zn	1.75	0.192	0.21	0.646	4.57	**0.038**
Ric*Myc*Zn	1.22	0.275	0.53	0.471	5.99	**0.018**
Int*Myc*Zn	0.04	0.848	11.88	**0.001**	5.46	**0.024**
Ric*Int*Myc*Zn	1.91	0.173	17.92	**0.000**	4.81	**0.033**

From Figure 9(A, B, C, D), it can be seen that the effect of Zn-S fertilization is very dominant and significant in producing a significant interaction effect between Zn-S fertilization and other treatment factors, such as rice types and cover crop species. This significant interaction effect produces the highest mean value of cover crop biomass (54.5 g/pot) (Figure 9(A)) and LER value (1.53) (Figure 9(B)) in the P2Z1 treatment combination. Likewise, the interaction between Zn-S fertilization and cover crop types produced the highest rice biomass (72.4 g/pot) (Figure 9(C)) and LER (1.55) (Figure 9(D) in the C2Z1 treatment combination.

In addition to the two-way interaction effects presented in Figures 7 to 9, there are also three-way and four-way interaction effects (Figures 10 to 13). From Figure 10, it can be seen that rice biomass is more dominantly influenced by the application of mycorrhiza biofertilizer (M1) so that the highest rice biomass was in white rice planted with peppermint and supplied with mycorrhiza biofertilizer (P2C2M1), followed by black rice in the combination of P1C2M1 and P1C1M1 treatments (Figure 10(A)), while the highest cover crop biomass was in peanut (C1) that received Zn-S fertilization and supplied with mycorrhiza biofertilizer (C1M1Z1).

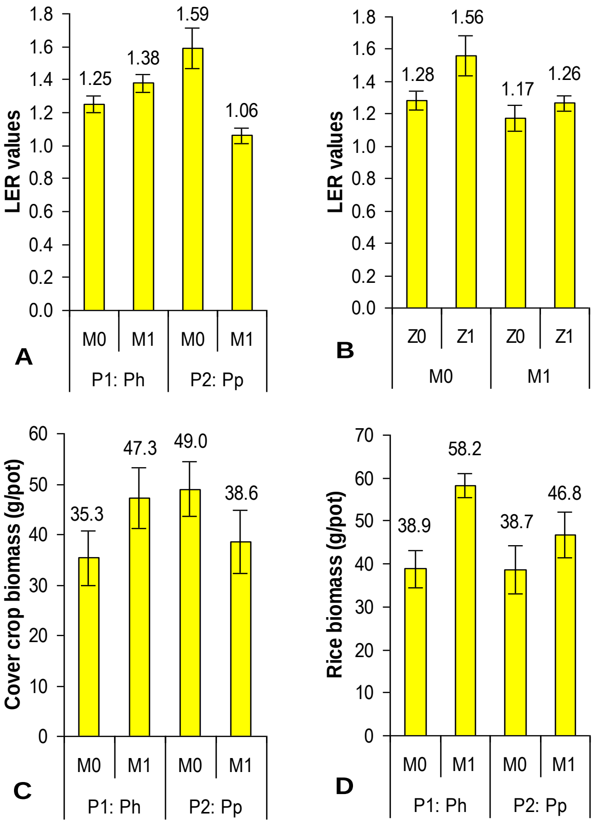


Figure 8. The effect of the interaction of two factors: (A) Rice types and mycorrhiza on land equivalent ratio (LER) values; (B) Mycorrhiza and zinc on LER values; (C) Rice types and mycorrhiza on cover crop biomass; (D) Rice types and mycorrhiza on rice biomass

The highest peanut biomass (73.70 g/pot) in C1M1Z1 (Figure 10(B)) is a contribution from the highest peanut biomass in the combination of P2C1M1Z1 and P1C1M1Z1 (Figure 11). So, most of the highest biomass in rice and cover crops in intercropping occurred due to the contribution of the application of mycorrhiza biofertilizer (M1) and/or Zn-S fertilization (Z1). In the intercropped rice, the highest rice biomass was in white rice (P2) intercropped with peppermint and supplied with mycorrhiza biofertilizer (62.74 g/pot), but this was not significantly different from the same rice plant without mycorrhiza biofertilizer (53.31 g/pot) and black rice supplied with mycorrhiza biofertilizer either intercropped with peppermint (59.05 g/pot) or peanut (57.35 g/pot) (Figure 10(A)). These indicated that intercropping with peanut imposed more severe competition for rice growth than intercropping with peppermint, probably due to the smaller size of peppermint than peanut in general (Figure 10(B)).

In contrast, Zn-S fertilization significantly increased cover crop biomass and resulted in the highest peppermint (49.2 g/pot) and peanut biomass (76.6 g/pot), although intercropped with the white rice (Figure 11). However, both types of these cover crops showed contrasting responses to Zn-S fertilization, in which the highest biomass weight of peanut was obtained when it was supplied with mycorrhiza biofertilizer, while that of peppermint was obtained without mycorrhiza biofertilizer. This phenomenon could indicate that the peanut was more responsive to mycorrhiza biofertilizer, while peppermint was more responsive to Zn-S fertilization. However, these require further investigations in relation to the effort to increase the production of these crops.

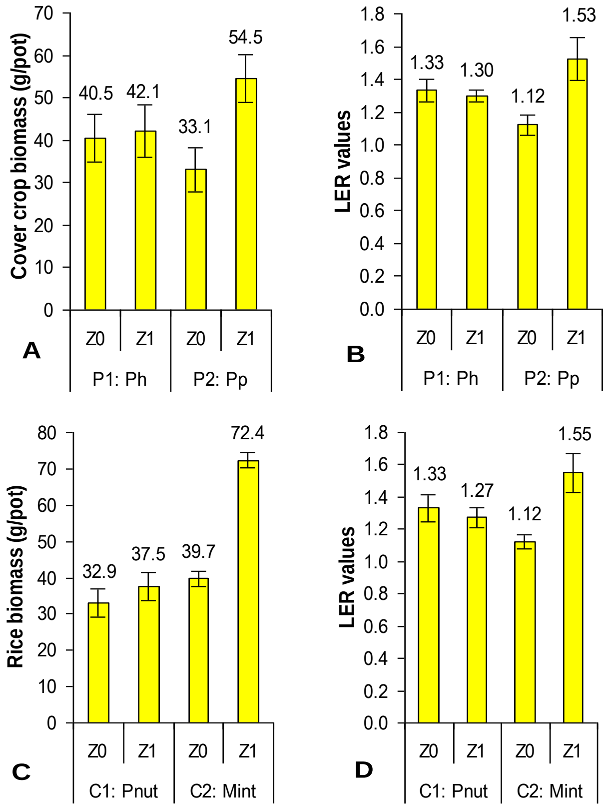


Figure 9. The effect of the interaction of two factors: (A) Rice types and Zinc on cover crop biomass; (B) Rice types and Zinc on land equivalent ratio (LER) value; (C) Intercropping and Zinc on rice biomass; (D) Intercropping and Zinc on LER values

What was significant is that application of mycorrhiza biofertilizer and Zn-S fertilization to these cover crops and rice plants, which were grown under upland conditions following the use of the soil to grow flooded rice, showed a significant increase in biomass weight of all crops compared to without application of mycorrhiza biofertilizer or Zn-S fertilization, both in sole and intercropping systems. These indicated the importance of mycorrhiza biofertilizer and/or Zn-S fertilization for upland crops grown following flooded rice. As commonly known that in Indonesia, rice is generally planted with a flooded system, and continuous flooding due to the use of rice fields for flooded rice cultivation has been reported to reduce the availability of Zinc in the soil of rice fields after the rice is flooded [5]. In addition, flooded rice systems normally reduce infective propagules of AMF [21, 22, 36], and under submergence, the availability of both P and Zn can be reduced due to the formation of Zinc Phosphate, which is not available for plant uptake [31]. These are the possible conditions resulting in the significant effects of mycorrhiza biofertilizer and Zn-S fertilization, and their synergistic effects on white rice biomass weight (Figure 3), as well as peanut and peppermint biomass (Figure 6), but only under sole cropping systems.

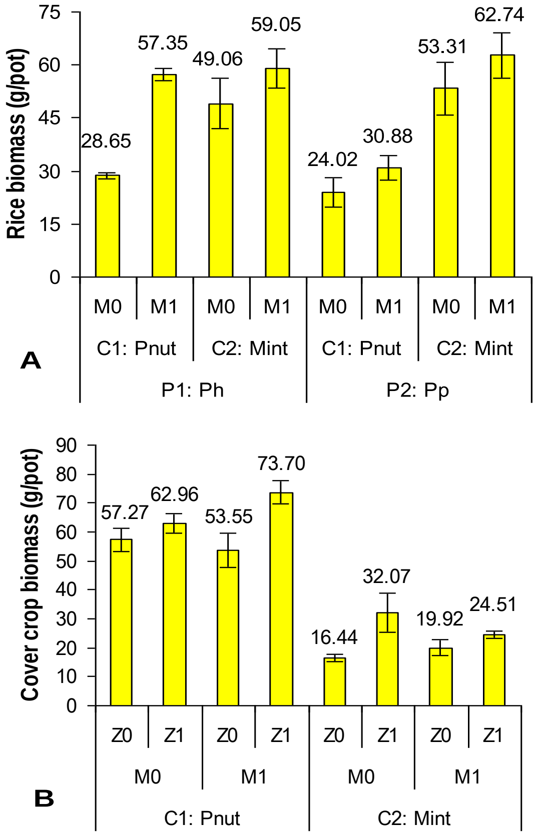


Figure 10. The effect of the interaction of three factors: (A) Rice types, intercropping, and mycorrhiza on rice biomass; (B) Intercropping, mycorrhiza, and zinc on cover crop biomass

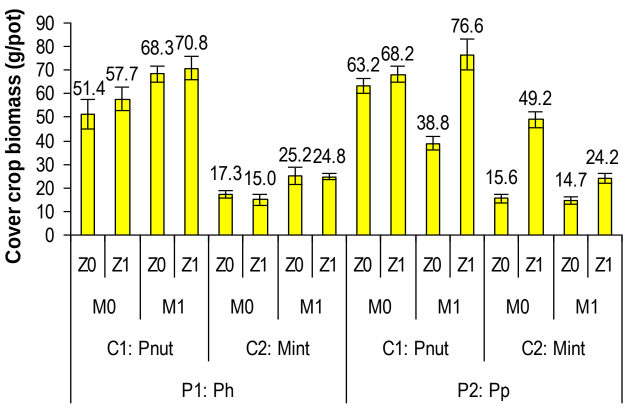


Figure 11. The effect of the interaction of four factors between rice types, intercropping, mycorrhiza, and Zn-S on cover crop biomass under the intercropping system

Those synergistic effects indicate good collaboration between mycorrhizal fungi and Zn-S in improving plant growth, especially in white rice, peanut, and peppermint in sole cropping. One of the positive roles of arbuscular mycorrhizal fungi is increasing nutrient uptake through the external hyphal network [37, 38], including Zn uptake [32]. In addition, the external hyphae of mycorrhizal fungi not only aid nutrient absorption but are also capable of dissolving nutrients, especially P and Zn, thus changing them from unavailable to available [39]. With this ability, it is highly possible that the synergistic effects observed in this study could occur. However, to find out what conditions exactly support these synergistic effects to occur, further investigations are recommended.

When associated with LER of the intercropping, the highest values were contributed by the combination of treatments M0Z1 applied to white rice (Figure 12(A)) intercropped with peppermint (Figure 12(B)), which were fertilized with Zn-S (Z1) but without mycorrhiza biofertilizer (M0). These are in line with the highest biomass of peppermint (49.2 g/pot) under M0Z1 intercropped with white rice (Figure 11). However, white rice biomass was highest (62.74 g/pot) under intercropping with peppermint supplied with mycorrhiza biofertilizer (Figure 10(A)).

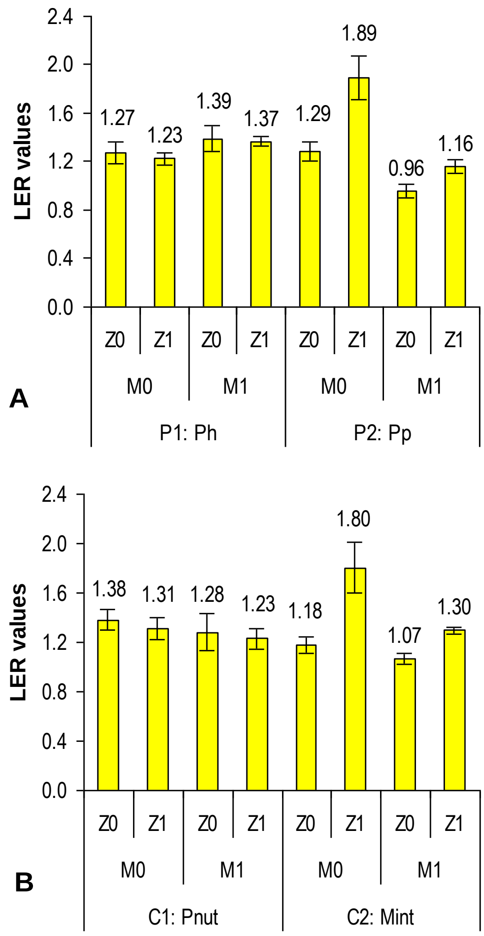


Figure 12. The effect of the interaction of three factors: A. Rice types, mycorrhiza, and Zinc on the land equivalent ratio (LER) values, and B. Intercropping, mycorrhiza, and Zinc on the LER values

When LER values were plotted using the four-way interaction effect, which was significant (Table 3), it can be seen from Figure 13 that the effect of Zn-S fertilization was highly significant in increasing LER values of the intercropping, resulting in the highest LER value (2.32) of white rice intercropped with peppermint under Zn-S fertilization but without application of mycorrhiza biofertilizer (Figure 13). This occurrence is thought to be due to the peppermint biomass in sole planting being very low (59.55 g/pot) (Figure 6) and the lower biomass weight of white rice in sole planting (47.90 g/pot) (Figure 3) compared with those in the intercropping system, thus supporting the higher LER value of 2.32 (Figure 13) under M0Z1 treatment combination.

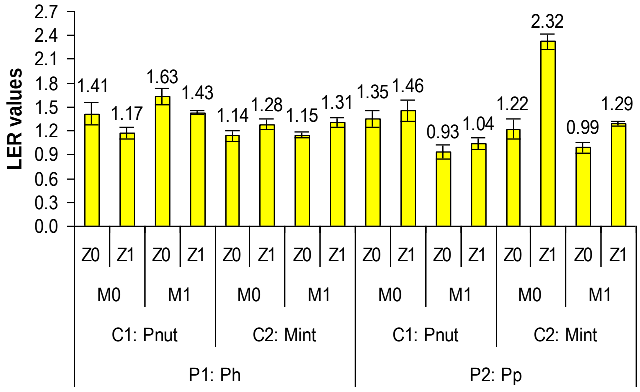


Figure 13. The effect of the interaction of four factors between rice types, intercropping, mycorrhiza, and Zinc on the land equivalent ratio (LER) values

However, the effect of Zn-S fertilization in this study cannot be separated into the effect of Zn and the effect of S fertilization because the Phonska plus fertilizer used in this study contains both S (9%) and Zn (0.2%) in addition to N, P, and K. In addition, both Zn and S contained in fertilizers applied to the soil cannot be 100% taken up by plant roots. For a long time, fertilization of rice with NPKSZn, Haque et al. [40] found that S fertilization efficiency was 9.3% in wet and 5.3% in dry season, while Zn fertilization efficiency was even lower, but other researchers reported that from Zn applied, upland rice can recover only on average 13% Zn [41]. In this study, Phonska plus was applied twice to rice with a total of 2 g/pot, so that S applied was 0.18 g/pot while Zn was 4 mg/pot. Therefore, theoretically, only 16.74 mg S and 0.52 mg Zn were taken up by rice plants per pot.

According to the Agronomy Fact Sheet by the University of California [42], the lowest sufficient level of S is 0.15% and Zn 25 ppm for rice. Therefore, for the mean values of rice biomass in Figure 3, it can be calculated that rice plants in the Z1 treatments need to take up 84.31 mg S and 0.84 mg Zn per pot without application of mycorrhiza biofertilizer (M0Z1 treatment). Thus, with a theoretical recovery rate of 16.74 mg S and 0.52 mg Zn from the Phonska plus fertilizer applied, it means that Zn-S fertilization supplied 61.9% of the Zn lowest sufficiency and only 19.9% of the S lowest sufficiency. However, compared to the treatments without Zn-S fertilization, the application of these amounts of Zn (4 mg/pot) and S (180 mg/pot) contained in the Phonska plus fertilizer of 2 g/pot, this Zn-S fertilization showed significant effect in increasing the biomass weight of rice plants, both in sole (Figure 3) and in intercropping, especially white rice (Figure 9(A)) in intercropping with peppermint (Figure 9(C)). Since plant and soil analyses were not carried out in this study, to separate the effect of each nutrient under Zn-S fertilization, with or without mycorrhiza biofertilizer, for more exact results, further investigations are recommended to be carried out under various conditions, either in sole or intercropping systems.

4. CONCLUSIONS

Based on the plant dry weights of the monocrops and LER of the intercropping, it can be concluded that the effects of mycorrhiza biofertilizer and Zn-S fertilization were significant in increasing dry weight of all crops, both in monocrop and in intercropping systems. These results mean that the availability of Zn-S and mycorrhiza infective propagules was low in the soil used in these pot experiments, which soil was continuously used previously to grow flooded rice for a long time. However, there were significant interaction effects, especially between mycorrhiza biofertilizer and Zn-S fertilization, and the interaction patterns indicated synergistic effects of the application of mycorrhiza biofertilizer and Zn-S fertilization in increasing the dry weight of those monocrops and LER values of the intercropping. Unfortunately, the data that can be recorded in these experiments were only the dry weight of those crops. For more comprehensive results, further investigations are needed, such as on how widespread and how serious the availability of Zn and S is in rice fields with a long history of use for growing flooded rice, and how each of these nutrients, as well as mycorrhizal fungi, affects the growth and yield of upland crops grown immediately following flooded rice.

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