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Effectiveness of arbuscular mycorrhizal fungi in increasing growth and yield of maize overlaid on oil palm aged 4 years

Abstract. The intercropping system in oil palm plantations is an effort to optimize land, especially at the immature stages (IS), which have a large open space between the trees, so it can be used for cultivating annual crops such as maize. Oil palm trees are generally planted on marginal lands, such as Inceptisol, which generally lacks in phosphor (P). These problems can be reduced by applying arbuscular mycorrhizal fungi (AMF) to elevate P. This experiment was to determine the dosage and effectiveness of AMF that can improve the growth and yield of maize intercropped with a 4-year-old oil palm. The experiment was conducted at the Ciparanje Experimental Station, Faculty of Agriculture, Universitas Padjadjaran, from February to May 2022. The experiment used a randomized block design (RBD) with six treatments and was repeated four times. The treatment consisted of giving AMF doses, which included: without AMF, 2 g AMF/plant, 4 g AMF/plant, 6 g AMF/plant, 8 g AMF/plant, 10 g AMF/plant. The results showed that the application of AMF can increase growth and better yield maize. A dosage of 10 g AMF/plant is the best treatment, increasing plant height, cob length, cob diameter, dry shelled weight, and 100 seed weight, each 3, 04%, 5.5%, 8.1%, 50.21%, and 8.42% compared to no AMF.

Keywords: Arbuscular mycorrhizal fungi · Intercropping · Maize · Oil palm

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Introduction

Oil palm (*Elaeis quineenensis* Jacq.) is an important plantation crop in the agricultural sector. Oil palm trees have a good prospect, due to the highest oil production among other vegetable oil-producing plants (Agung et al., 2019).

The area of oil palm plantations in Indonesia continues to increase yearly. Based on the Ministry of Agriculture data, in 2021, the area of palm oil plantations reached 15.08 million ha, with the largest portion held by private large plantations (PLP). The proportion of oil palm plantation by land ownership amounted to 8.42 million ha (55.8%) of PLP, followed by smallholder plantations (SP) of 6.08 million ha (40.34%), and national plantations (NP) of 579.6 thousand ha (3.84%). In total, the oil palm area is 15.08 million Ha, consisting of 12,593,035 Ha (83.50%) Producing Plants (PP), 450,585 Ha (2.99%) are damaged plantations (DP), and 2,037,401 Ha (13 .51%) are Immature Plants (IP) (Statistics Indonesia, 2021).

In Oil palm plantations, the trees are generally planted in an equilateral triangle pattern, with a spacing of 9 m x 9 m x 9 m with a population of 143 trees/ha. This wide spacing causes there is large open space among the trees at IS. This open space is potentially growing by many kinds of weeds leading to reduce soil fertility and harmful oil palm trees. To minimize this condition, the growing annual crop such as maize in the intercropping system can be an alternative in the oil palm plantation. Maize is the main food commodity after rice which has a strategic role in agricultural and economic development such as providing food and industrial raw materials. In Indonesia, the demand for maize always increases yearly (Ministry of Agriculture, 2021).

Good maintenance, such as fertilizer addition, can achieve high productivity of maize. One of the problems in oil palm plantations is that they are generally planted on marginal soils, such as inceptisols, which have limited chemical fertility, especially element P. Therefore, the way to increase the productivity of maize plants can be done by applying arbuscular mycorrhizal fungi (AMF) biofertilizers because they are capable of symbiosis with 90% of plant species (Smith & Read, 2008).

Arbuscular mycorrhizal fungi are inoculants made from active living organisms that facilitate the availability of nutrients, especially P, in the soil for plants (Husna et al., 2015). Utilization of this AMF is one of the alternatives in increasing soil fertility and supporting sustainable agriculture because it can reduce the use of fertilizers and inorganic materials to produce healthier maize feed. This study was to determine the dose of AMF that can improve the best growth and yield of maize intercropped with a 4-year-old oil palm

Materials and Methods

The experiment was carried out at the Ciparanje Experimental Garden, Faculty of Agriculture, Padjadjaran University, Jatinangor, an altitude of ± 780 m above sea level (asl). Inceptisol soil order, climate type C based on the classification of Schmidt and Ferguson (1951). The trial starts from February to May 2022.

The planting materials used were hybrid maize of the Pertiwi variety 3 and oil palm of the SEU Supreme variety, 48 months old. The other ingredients are NPK fertilizer, chicken manure, and consortium AMF inoculant, which consists of 4 species, namely Gigaspora sp., Glomus sp., Entropospora sp., and Acaulospora sp.

The design used was a randomized block design (RBD), consisting of six treatments and repeated four times so that there were 24 experimental units. The treatment plan consists of:

A = without AMF
B = 2 g AMF/plant
C = 4 g AMF/plant
D = 6 g AMF/plant
E = 8 g AMF/plant
F = 10 g AMF/plant

Observational data were tested by analysis of variance (Anova), if they were significantly different, the test was continued with Duncan's multiple range test at 95% confidence level (Gomez and Gomez, 1995)

The plant distance between maize and oil palm was 1.5 m. At the oil palms row there was maize trial plot of 4.5 m x 4.5 m The distance between maize plants was 75 cm x 20 cm and Corn planting is done between rows of oil palms. Land preparation begins with clearing weeds and loosening the soil, then making beds.

Maintenance for maize plants includes fertilizing, hilling, weed control, watering, and pest and disease control. Basic fertilizer is given as chicken manure, as much as 15 tons/ha or 24 kg for one plot of maize plants. Further fertilization was carried out in the form of 300 kg/ha or 480 g/plot of urea, 100 kg/ha or 160 g/plot of SP-36, and 100 kg/ha of KCl or 160 g/plot. SP-36 and KCl fertilizers were given at 2 WAP, while urea fertilizer was given twice, namely at 2 WAP and 7 WAP.

The application of AMF was carried out once according to the treatment dose, carried out shortly before planting maize by mixing AMF in the planting hole, then planting maize seeds and covering them again with soil. Harvesting of maize plants was done when the maize cobs are ripe with the characteristics of yellowing leaves, yellowish husks, and brown hair on cobs. Variables observed included degree of root infection, index of chlorophyll content, stomatal conductance, plant height, stem diameter, leaf area, and yield components of maize plants (cob length, cob diameter, weight of 100 seeds, and weight of shelled seeds per plant).

Results and Discussion

Percentage of root infection. Table 1 shows that the treatment at a dose of 10 g AMF/plant resulted in a significantly different percentage response to root infection than the other treatments, but not significantly different from treatment E (8 g AMF/plant).

The data shows that there is a tendency for the higher the application of AMF to maize plants, the higher the percentage of infection that occurs in plant roots. This is in accordance with the research of Jamilah et al. (2016); the higher the AMF inoculated in plants, the higher the percentage of AMF colonization on the roots.

Table 1. Effect of AMF dosage on the degree of root infection of maize plants among oil palm plantations age 4 years.

Perlakuan	Degree of Root Infection (%)
A (No AMF)	51.67 a
B (2 g AMF/Plant)	61.67 ab
C (4 g AMF/Plant)	60.00 a
D (6 g AMF/Plant)	63.34 ab
E (8 g AMF/Plant)	76.67 bc
F (10 g AMF/Plant)	79.17 c

Note: The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

Mycorrhizal plant roots will be able to increase the capacity to absorb nutrients and water so that the absorption of nutrients needed by plants can run better. This situation is supported by a suitable growing environment for the development and activities of AMF (Suherman & Ridho, 2014).

Maize chlorophyll content index. Table 2 shows that, at the 8th and 10th WAP observations, all treatments with AMF doses produced a larger and significantly different chlorophyll content index than those without AMF.

Table 2. Effect of AMF dosage on the chlorophyll content index of maize plant leaves among oil palm plantations.

Treatment	Chlorophyll content index (cci)			
	4 WAP	6 WAP	8 WAP	10 WAP
A (No AMF)	24.27 a	28.32 a	36.36 a	44.94 a
B (2 g AMF/Plant)	24.79 a	29.07 a	38.36 b	48.19 b
C (4 g AMF/Plant)	24.68 a	28.05 a	38.33 b	48.16 b
D (6 g AMF/Plant)	26.77 b	30.25 a	39.16 bc	47.97 b
E (8 g AMF/Plant)	26.78 b	29.15 a	39.09 bc	48.31 b
F (10 g AMF/Plant)	27.41 b	30.74 a	39.61 c	48.50 b

Note: WAP-weeks after planting. The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

Chlorophyll plays a role in capturing sunlight in the process of photosynthesis (Agustamia et al., 2016). A more efficient chlorophyll content in maize plants was found at 10 WAP observations. treatment of 2 g of AMF/plant produced the same chlorophyll content index. It was not significantly different from the result of higher AMF application, but significantly different from no AMF application. Providing more AMF besides being able to increase the absorption of nutrient P, other physiological aspects that are affected by AMF include water uptake (Davies et al., 1996), nitrogen fixation and resistance to root disease (Linderman, 1996), nitrogen element, plays an important role as a synthetic material chlorophyll, proteins, and amino acids.

Maize plant stomata conductance. Table 3 shows that, for each observation time, consistent doses of 10 g AMF/plant resulted in significantly different stomatal conductance than the treatment without AMF.

Stomata conductance will determine the yield, especially on the quality of maize seeds. Plants that have greater stomatal conductance have the potential to have high production (Sabagh et al., 2017). It is suspected that symbiotic mycorrhizae in plant roots will help plants more optimally absorb water molecules in the soil. This is in line with the opinion of Nyland (1996) who states that plants will grow well if the soil contains AMF because, through symbiosis, plants can absorb more water and nutrients.

According to Lestari (2006), plants colonized by AMF colonizes will obtain sufficient nutrients from the soil, especially the K element already available in the soil. K is an essential nutrient in maintaining turgor pressure and regulating stomatal openings to improve plant growth. Stomata conductance is affected by carbon dioxide concentration, temperature, humidity, wind, light, and rainfall.

Plant height. Table 4 shows that, at the 4th week after planting (WAP), the application of AMF did not produce a significantly different plant height response but starting from the 6th, 8th, and 10th weeks of WAP observation, the application of AMF produced a different plant height response real.

Plant height at 8 and 10 WAP showed that all treatments with AMF produced a response to plant height that was higher and significantly different compared to the response to no AMF treatment. Data Table 4, shows that, a dose of 2 g of AMF/plant increased plant height by 2.6%, compared to no AMF, and was not significantly different from the height of plants given a higher AMF dose. This is in line with the effect of AMF dose on chlorophyll content index (Table 2.), that the application of 2 g AMF/plant, produced the same chlorophyll content index response as at a dose of 4-10 g AMF/plant. It is suspected that at this dosage, the presence of AMF is quite optimal, to support the availability of nutrients that enable good plant growth. One of the mechanisms by which AMF works in supporting nutrient availability is by releasing the phosphatase enzyme, which functions to break down unavailable P, to become available. The availability of elements that are difficult for plants to absorb becomes available to plants, will spur growth in plants (Zakiah and Fika, 2018). Application of 10 g of AMF/plant increased plant height by 3.04% compared to no AMF treatment.

Table 3. Effect of AMF dosage on stomatal conductance of maize plants among oil palm plantations.

Treatment	Stomatal Conductance (mmol H_20/m^2s)			
	4 WAP	6 WAP	8 WAP	10 WAP
A (No AMF)	193.50 a	146.91 a	169.05 a	168.48 a
B (2 g AMF/Plant)	246.55 a	172.21 b	194.91 a	180.93 ab
C (4 g AMF/Plant)	251.71 a	168.56 b	183.85 a	189.72 ab
D (6 g AMF/Plant)	216.94 a	183.30 b	246.14 b	188.38 ab
E (8 g AMF/Plant)	264.16 ab	184.41 b	230.77 b	192.58 ab
F (10 g AMF/Plant)	337.17 b	186.39 b	260.94 b	199.66 b

Note: WAP-weeks after planting. The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

Table 4. Effect of AMF dosage on maize plant height among oil palm plantations.

Treatment	Maize Plant Height (cm)			
	4 WAP	6 WAP	8 WAP	10 WAP
A (No AMF)	96.46 a	160.06 a	220.75 a	257.56 a
B (2 g AMF/Plant)	98.30 a	166.94 ab	230.81 b	264.16 b
C (4 g AMF/Plant)	98.56 a	168.31 ab	231.44 b	264.50 b
D (6 g AMF/Plant)	99.21 a	169.38 ab	230.38 b	264.38 b
E (8 g AMF/Plant)	98.40 a	168.59 ab	231.00 b	264.90 b
F (10 g AMF/Plant)	101.75 a	174.69 b	237.13 b	265.39 b

Note: WAP-weeks after planting. The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence

Table 5. Effect of AMF dosage on stalk diameter of maize plants among oil palm plantations.

Treatment	Stalk Diameter (cm)			
	4 WAP	6 WAP	8 WAP	10 WAP
A (No AMF)	1.70 a	2.51 a	2.64 a	2.76 a
B (2 g AMF/Plant)	1.71 a	2.54 a	2.66 a	2.77 a
C (4 g AMF/Plant)	1.73 a	2.51 a	2.65 a	2.80 a
D (6 g AMF/Plant)	1.72 a	2.51 a	2.62 a	2.80 a
E (8 g AMF/Plant)	1.72 a	2.51 a	2.66 a	2.81 a
F (10 g AMF/Plant)	1.72 a	2.57 a	2.67 a	2.83 a

Note: WAP-weeks after planting. The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

Stalk diameter. Table 5 shows that all doses of AMF did not produce a significantly different maize stalk diameter response. Nevertheless, there is a tendency, an increase in the provision of AMF, numerically tends to increase the stem diameter. At 10 WAP observations, the application of AMF increased the diameter of the maize stalks by up to 2.5% compared to no AMF treatment.

The growth of maize stalk diameter is influenced by two factors, namely genetic factors and environmental factors such as soil fertility

Leaf area. Table 6 shows that the application of AMF doses did not produce significantly different leaf area responses in maize plants. This is presumably because the leaf area has increased significantly due to the low intensity of sunlight. According to Buntoro et al, (2014), the leaf area is affected by the intensity of sunlight. The low intensity of sunlight causes the thickness of the leaves to become thinner, but the leaf area increases significantly. Leaf area is closely related to the amount of photosynthesis produced by plants from photosynthesis. The greater the photosynthate produced by the plant, the greater the photosynthate translocated to the plant parts.

Maize cob length and diameter. Table 7 shows that the application of AMF doses resulted in significantly different responses to the length and diameter of the maize cobs. Treatment at a dose of 10 g AMF/plant gave greater and significantly different cob length and diameter compared to cob length and diameter that were not treated with AMF. The calculation results show that giving 10 g of AMF/plant increases cob length by 5.5%, compared to not giving AMF. While the cob diameter increased by 8.1% compared to no AMF treatment. Roots infected with mycorrhizal fungi have a greater capacity to absorb nutrients than plants not infected with mycorrhizal fungi. (Sagala, 2013). In accordance with the opinion of Sintia (2011), providing balanced nutrients can increase maize yields in terms of cob quality.

Table 6. Effect of AMF dosage on maize leaf area among oil palm plantations.

Treatment	Leaf Area (cm^2)
A (No AMF)	711.68 a
B (2 g AMF/Plant)	713.43 a
C (4 g AMF/Plant)	705.43 a
D (6 g AMF/Plant)	714.41 a
E (8 g AMF/Plant)	723.02 a
F (10 g AMF/Plant)	728.45 a

Note: The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

Table 7. Effect of AMF dosage on maize cob length and diameter among oil palm plantations.

Treatment	Cob Length (cm)	Cob Diameter (cm)
A (No AMF)	19.82 a	5.57 a
B (2 g AMF/Plant)	20.19 ab	5.68 ab
C (4 g AMF/Plant)	20.13 ab	5.64 a
D (6 g AMF/Plant)	20.13 ab	5.69 ab
E (8 g AMF/Plant)	20.50 ab	5.74 ab
F (10 g AMF/Plant)	20.91 b	6.02 b

Note: The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

Based on the cob diameter data, mycorrhizal doses influence the formation of maize cob diameter. This is because of mycorrhiza can increase macronutrients and some microelements. According to Budiman (2004), element P is an element needed in large quantities in the formation of maize cobs. Low P conditions in the soil will increase the role of AMF in helping to release total P to become available P because AMF produces organic acids which can release unavailable P to become available P (Syamsiyah et al., 2014).

Dry-shelled weight per plant and 100 maize kernels. Table 8 shows that, in general, the application of AMF increased the weight of dry-shelled seeds planted between 36.06-50.21%, compared to no AMF treatment. Treatment at a dose of 4 g AMF/plant resulted in higher dry shell weight/plant and was significantly different than without AMF, but not significantly different from the effect of other treatments. Giving AMF to maize plants can increase the absorption of plant nutrients so that it has a significant effect on maize seed production

This study's results align with Sukiman's study (2010), which showed an increase in the yield of dry-shelled maize with AMF application could provide better results than without AMF application. This is presumably because AMF-infected plants, through their external hyphae network, expand the penetration of root uptake so that the plants obtain an adequate supply of nutrients for growth and an increase in maize yields.

The application of AMF also significantly affected the weight of 100 seeds (Table 9). The table shows that the provision of AMF increased the weight of 100 seeds between 2.00-8.42% compared to no AMF. Dosing 10 g AMF/plant produced a larger and significantly different weight of 100 seeds compared to no AMF treatment, but not significantly different from the other treatments.

Table 8. Effect of AMF dosage on dry seed weight among oil palm plantations

Treatment	Dry Seed Weight per plant (g)
A (No AMF)	89.19 a
B (2 g AMF/Plant)	125.96 ab
C (4 g AMF/Plant)	129.93 b
D (6 g AMF/Plant)	121.35 ab
E (8 g AMF/Plant)	133.12 b
F (10 g AMF/Plant)	133.97 b

Note: The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

Table 9. Effect of AMF dosage on the weight of 100 maize seeds between oil palm plantations

Treatment	Weight of 100 Maize Seeds (g)
A (No AMF)	21.27 a
B (2 g AMF/Plant)	21.94 ab
C (4 g AMF/Plant)	22.48 ab
D (6 g AMF/Plant)	21.69 ab
E (8 g AMF/Plant)	22.51 ab
F (10 g AMF/Plant)	23.06 b

Note: The mean value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at the 95% level of confidence.

The higher dried weight of seeds per plant was supported by the formation of larger seeds. This is indicated by the higher weight of 100 seeds. The weight of 100 dry-shelled maize kernels is largely determined by photosynthate accumulation during the seed filling phase. The presence of AMF in the roots of maize plants allows for increased absorption of water and nutrients, including P nutrients by plants, so that they can meet plant needs in the process of forming and filling seeds (Kuik, 2022).

Conclusion

1. The application of AMF effectively increase growth and yield of maize plants. Plants

treated with AMF have better results than plants without AMF.

2. Giving a dose of 10 g AMF/plant is the best treatment, increasing plant height, cob length, cob diameter, dry shelled weight, and 100 seed weight, respectively 3,04%, 5,5%, 8,1%, 50,21%, and 8,42% compared to no AMF.

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