



Effect of Fungi Mycorrhizal Arbuscular (FMA) Dosage on the Growth and Yield of Shallots (*Allium cepa* var. *aggregatum*) in Ultisol

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Authors' contributions

This work was carried out in collaboration among all authors. Authors DAD, NS, and MH contributed to the design and wrote the first draft of the manuscript. Authors YHB and SA edited and reviewed the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aims to determine the optimal dosage of Fungi Mycorrhizal Arbuscular (FMA) to enhance the growth and yield of shallots (*Allium cepa* var. *aggregatum*) in Ultisol.

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Study Design: The research was conducted from February to April 2024 at the Agronomy Experimental Station and Laboratory, Faculty of Agriculture, University of Bengkulu, at an altitude of ± 10 m above sea level.

Methodology: A completely randomized design (CRD) with one factor was used, consisting of five FMA dosage treatments (0, 10, 20, 30, and 40 g inoculant/plant), with four replications, resulting in 20 experimental units. Each unit consisted of three plants, totaling 60 shallot plants.

Results: The application of FMA significantly influenced shallot growth and yield, particularly fresh and dry shoot weight and fresh onion bulb weight. At a 40 g inoculant/plant dose, FMA can increase fresh and dry shoots and bulb weight by 24.83%, 2.51%, and 50.65%, respectively, compared to without FMA application.

Conclusion: The application of FMA at a dosage of 40 g inoculant/plant effectively enhances shallot growth and yield, particularly in shoot and bulb weight.

Keywords: Shallot; Fungi Mycorrhizal Arbuscular (FMA); inoculant; ultisol; sustainable agriculture.

1. INTRODUCTION

Shallots (*Allium cepa* var. *aggregatum*) are a vital horticultural crop widely cultivated for their culinary and economic value, particularly in tropical and subtropical regions. However, their productivity is often constrained by poor soil fertility, especially in Ultisols. Ultisols typically exhibit acidic pH, low cation exchange capacity (CEC), and limited availability of essential nutrients like phosphorus, which is often fixed by aluminum. Ultisols can support agriculture with proper management practices such as liming, organic matter addition, and fertilization to improve soil fertility and productivity (Sanchez, 2019; Soelaeman & Haryati, 2012).

To address these challenges, sustainable agricultural practices, such as the application of Fungi Mycorrhizal Arbuscular (FMA), have gained attention for their potential to enhance nutrient uptake, improve soil structure, and promote plant growth (Smith & Read, 2015). The role of FMA in improving crop performance has been extensively studied, with evidence suggesting that these fungi can significantly enhance plant growth, yield, and stress tolerance (Bowles et al., 2018; Arraudah et al., 2020; Septiani et al., 2021).

However, the effectiveness of FMA inoculation is highly dependent on the dosage applied, as insufficient and excessive amounts can lead to suboptimal results (Sudantha & Astiko, 2020; Rini et al., 2022). Determining the appropriate FMA dosage is crucial for maximizing the benefits of this symbiotic relationship, particularly in challenging soil conditions like Ultisols. Despite the growing body of research on FMA, there is a lack of specific studies focusing on the optimal dosage for shallot cultivation in such soils.

Recent studies have highlighted the potential of FMA to improve the growth and yield of various crops, including shallots (Ridwan & Prasetya, 2019; Warman et al., 2022). However, the specific mechanisms by which FMA enhances shallot performance in Ultisols remain underexplored. Furthermore, the interaction between FMA dosage and soil properties in Ultisols requires further investigation to develop tailored recommendations for farmers. This study aims to fill this gap by evaluating the effect of different FMA dosages on the growth and yield of shallots in Ultisol soils.

Understanding the optimal FMA dosage for shallot cultivation in Ultisols is essential for improving crop productivity and promoting sustainable agricultural practices. By reducing the reliance on chemical fertilizers, FMA application can contribute to environmental conservation and long-term soil health (Powell & Rillig, 2018). The research aims to determine the dosage of FMA (Fungi Mycorrhizal Arbuscular) fertilizer on the growth and yield of shallots in Ultisol.

2. METHODOLOGY

2.1 Location Site and Research Design

The research was conducted from February to April 2024 at the Experimental Station and Agronomy Laboratory, Faculty of Agriculture, University of Bengkulu, at an altitude of ± 10 m above sea level. The experimental design was a Completely Randomized Design (CRD) consisting of one factor with five treatment levels, namely doses of fungi mycorrhizal arbuscular (FMA) of 0, 10, 20, 30, and 40 g of inoculant/plant. Each treatment was repeated four times, and each experimental unit used three plants, a total of 60.

2.2 Soil Analysis

Soil analysis was carried out to determine pH, soil N, P, K and C-organic content (%) and Al content.

2.3 Medium Preparation

The soil used was Ultisol, taken from a depth of 20 cm from the soil surface. The soil was air-dried and sieved with a 2 mm sieve. Furthermore, the soil was mixed with cow manure and rice husk charcoal with a ratio of 2:1:1 v/v. The mixture of soil, cow manure, and rice husk charcoal as a planting medium was put into a polybag 8 kg, then arranged with a distance between polybags of 20 cm x 20 cm. The shallot bulbs planted were the Bima Brebes variety, which was 60 days old, and the bulb weight was between 3-4 g.

2.4 Basic Fertilizer Application

The recommended essential fertilizer dosage for shallots is urea = 250 kg/ha, KCl = 100 kg/ha, and SP-36 = 150 kg/ha (100%). This study, SP-36 was applied at 25% of the recommended dose, equivalent to 37.5 kg/ha, while urea and KCl were maintained at full dosage. Consequently, each shallot plant in a polybag received 1.25 g of urea, 0.50 g of KCl, and 0.19 g of SP-36. The base fertilizer was applied one week before planting by evenly distributing it around the plants.

2.5 Fungi Mycorrhizal Arbuscular (FMA)

Mycorrhizal application is carried out at planting with doses according to the treatment, namely 0, 10, 20, 30, and 40 g of inoculant/plant. Mycorrhizal application is carried out by inserting it directly into the planting hole at a depth of 3 cm.

2.6 Planting and Harvesting

Shallots were planted in the planting hole in the middle of the polybag that has been given FMA. Each polybag was planted with two shallot bulbs in a standing planting position where the growing point of the shallot bulbs is upward. Watering was done to maintain soil moisture; replanting was done 7 days after planting (DAP); weeding was done manually. Fungicide with the active ingredient mancozeb 80% was used with a dose of 2 g / liter of water to prevent fusarium wilt disease attacks 3 and 4 weeks after planting.

Harvesting is done when the shallot plants are 60 days old after planting or have met the harvest criteria, with the characteristics of the leaves starting to wilt and turn yellow, the leaves falling to the surface of the soil, the stems limp, some of the bulbs have appeared on the surface of the soil, and the color of the bulb layer is red.

2.7 Data Collection and Analysis

The data were analyzed statistically using an Analysis of Variance (ANOVA) of 5%. If the F test results had a significant effect, further testing was carried out using the DMRT 5% test.

3. RESULTS AND DISCUSSION

3.1 Plant Height and Leaves Number

The growth pattern of shallots in the vegetative phase, both plant height and number of leaves from 2 to 6 weeks after planting (WAP), is described as follows.

3.1.1 Plant height

The growth of shallots exhibited a consistent weekly increase, with plant height expanding by approximately 2–3 cm per week across all treatments. The highest average plant height, measuring 29.42 cm, was observed in the treatment with a 40 g inoculant/plant dose. According to existing descriptions, the Brebes variety typically attains a height ranging from 25 to 44 cm. Muhammad et al. (2023) reported that applying arbuscular mycorrhizal fungi resulted in Bima Brebes shallots with an average height of 30 cm. The greater plant height observed at the 40 g inoculant /plant dose is likely attributed to enhanced nutrient availability due to mycorrhizal activity, enabling optimal nutrient absorption. Similarly, studies by Laila et al. (2019) and Muhammad et al. (2023) demonstrated that mycorrhizal application promoted increased shallot plant height, ultimately contributing to higher yields.

The application of fungi mycorrhizal arbuscular (FMA) enhances nutrient uptake, particularly phosphorus (P), copper (Cu), and zinc (Zn) (Nurhayati, 2012). Phosphorus plays a crucial role in root development, thereby improving nutrient absorption efficiency. Copper is involved in photosynthetic processes, particularly electron transfer, while zinc is a co-factor for the phosphodiesterase enzyme (KE, 2007). The carbohydrates generated through photosynthesis

contribute to protoplasm formation in meristematic tissues, ultimately promoting plant height growth.

3.1.2 Number of leaves

Leaves are essential plant organs and key to assessing plant growth and development. A greater number of leaves enhances the photosynthetic process, leading to increased production of photosynthates that are subsequently translocated to the tubers (Mukhlis et al., 2012). An optimal leaf number also significantly contributes to photosynthetic efficiency, ultimately promoting biomass accumulation. Plants with a higher leaf number exhibit enhanced photosynthetic capacity and generate more carbohydrates that can be stored in the tubers, thereby improving overall yield (Putra et al., 2024). Fig. 2 shows that the weekly increase in leaf number relatively consistent, with an average increment of 3–4 leaves across all treatments.

The Brebes variety of shallots generally produces between 14 and 50 leaves. In this study, the highest leaf number, averaging 24.91 leaves per plant, was observed in the treatment with a 40 g inoculant/plant dose. Muhammad et al. (2023) reported that shallots treated with FMA developed an average of 22 leaves 42 days after planting (DAP). One of the key functions of FMA is to enhance nitrogen (N) uptake by plant roots, thereby optimizing the photosynthetic process

and promoting leaf formation (Putra et al., 2024). FMA contributes to increased nitrogen availability in the soil through the activity of external hyphae, which improve soil structure and support nitrogen-fixing bacteria. This enhanced nitrogen absorption enables shallot plants to develop more leaves, ultimately improving overall productivity (Murni & Purnamayani, 2019). The findings indicate that the 40 g/plant inoculant treatment resulted in a higher leaf number than other treatments (Fig. 2).

3.2 Analysis of Variance of Growth and Yield of Shallots

Statistical analysis revealed that applying FMA at different doses had no significant effect on plant height, number of leaves per clump, leaf greenness, number of tubers per clump, tuber diameter, fresh and dry root weight, or harvest index. However, it significantly impacted fresh and dry shoot weight and fresh tuber weight, with a coefficient of variation ranging from 9.25% to 55.55% (Table 1).

3.3 The Effect of Fungi Mycorrhizal Arbuscular (FMA) Doses on the Growth and Yield of Shallots

FMA treatment significantly affected the shoot's fresh and dry weight and the tuber's fresh weight. The results of the DMRT further test are shown in Tables 2 and 3.

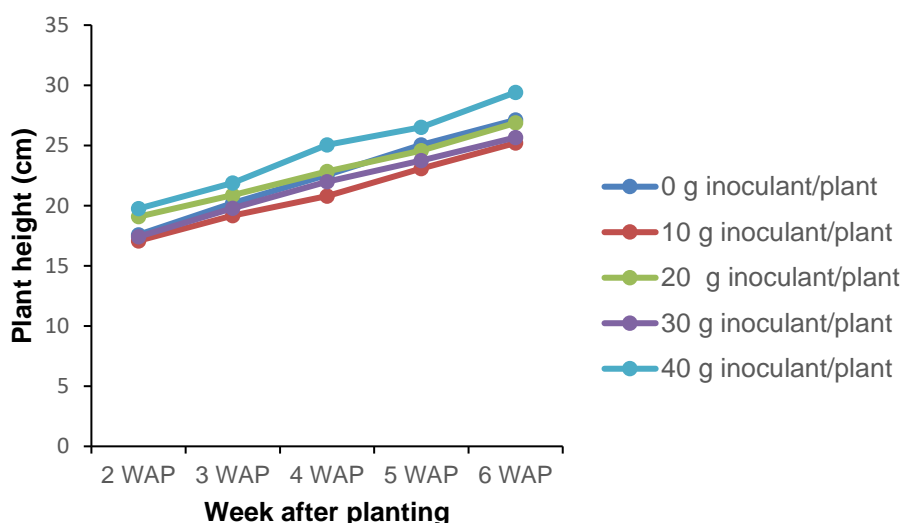


Fig. 1. Shallot Plant Height at 2 - 6 Week After Planting

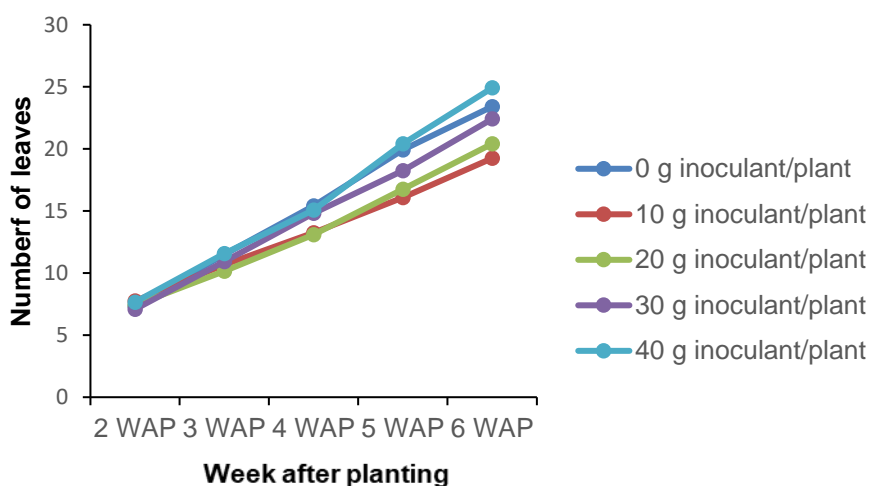


Fig. 2. Shallot leaves number at 2 - 6 week after planting

Table 1. Summary of variance analysis of FMA doses on shallot growth and yield

Variables	F- calculated	Coef. Variation %
Plant height (6 WAP)	1.74ns	9.25
Leaves number per clump (6 WAP)	0.9 ns	21.61
Leaf greenness	0.98ns	9.54
Bulb number per clump	1.41ns	24.55
Bulb diameter	1.34ns	17.97
Bulb fresh weight	4.91*	31.70
Root fresh weight	0.95ns	13.37
Shoot fresh weight	5.53*	26.36
Root dry weight	0.92ns	55.55
Shoot dry weight	4.91*	24.18
Harvest index	3.50ns	10.01

Note: ns: no significant effect, *: significantly different at the 5% level, CV: coefficient of variation.

Table 2. Effect of AMF dosage on shallot growth

Treatment	Observation Variable													
	PH (cm)	LN	LG (SPAD)	RFW (g)	SFW (g)	RDW (g)	SDW (g)							
T0	27.12	a	23.41	a	34.80	a	2.99	a	16.29	b	0.52	a	1.70	bc
T1	25.21	a	19.25	a	35.86	a	2.93	a	10.59	b	0.45	a	1.35	c
T2	25.87	a	20.41	a	34.25	a	3.32	a	14.82	b	0.49	a	1.47	c
T3	25.87	a	22.41	a	33.45	a	3.01	a	16.93	b	0.84	a	2.22	ab
T4	29.41	a	24.91	a	37.77	a	3.37	a	24.83	a	0.55	a	2.51	a

Description: T0 = (0 FMA inoculant treatment/plant), T2 = (10 g FMA inoculant/plant), T3 = (20 g FMA inoculant/plant), T3 = (30 g FMA inoculant/plant), T4 = (40 g FMA inoculant/plant), PH = Plant height (cm), LN = Leaves number, LG = Leaf greenness, RFW = Root fresh weight (g), SFW = Shoot fresh weight (g), RDW = Root dry weight (g), SDW = Shoot dry weight (g).

The number of bulbs per clump ranged from 7.00 to 8.83, while bulb diameter varied between 16.21 and 18.67. The highest fresh bulb weight was recorded in the T4 treatment (40 g inoculant/plant dose) at 50.63 g, whereas the lowest was observed in the T3 treatment at 21.64 g, which was not significantly different from the T1

treatment at 23.25 g. The harvest index ranged from 0.13% to 0.19%.

The results showed that shallot plant height ranged from 25.87 cm to 29.41 cm, while the number of leaves per clump varied between 19.25 and 24.91. Leaf greenness between 33.45

SPAD and 37.77 SPAD, whereas fresh root weight ranged from 2.93 g to 3.37 g. The highest fresh shoot weight was obtained from the T4 treatment (40 g inoculant/plant) at 24.83 g, while the lowest was observed in the T1 treatment at 10.59 g, which was not significantly different from the T0, T2, and T3 treatments. The dry root weight ranged between 0.45 g and 0.84 g, with the highest dry shoot weight recorded in the T4 treatment at 2.51 g. In contrast, the lowest dry shoot weight was observed in the T2 treatment at 1.47 g, which did not significantly differ from the T0, T1, and T3 treatments (Table 2).

The FMA population increased across all treatments. Inoculants at a dose of 40 g/plant produced the highest FMA population, followed by P uptake (Fig. 3). Rahman et al. (2019) reported that FMA application enhances plant phosphorus uptake. According to Muzaffarsyah (2022), FMA produces organic acid enzymes that improve phosphorus (P) absorption in plants. There were nine spores in the control treatment (0 g inoculant/plant), with a P absorption of 0.15. The presence of P in the control plants was due to the addition of organic fertilizer. Organic fertilizer affects FMA activity. This study's results align with those of Bunn et al. (2019), who state that FMA can colonize litter and organic matter.

In addition, FMA plays an important role in increasing nutrient absorption, and increased nutrient absorption positively affects plant growth and yield. In addition, FMA application also increases plant tolerance to environmental stress, such as drought and salinity (Arisma et al., 2024).

FMA inoculant at a dose of 40 g/plant increases the growth and yield of shallots. Thus, at a dose of 40 g inoculant/plant. Fungi Mycorrhizal Arbuscular (FMA) facilitate shallot bulb formation by enhancing phosphate uptake, which is crucial for carbohydrate metabolism and bulb development. Additionally, FMA contributes to increasing bulb weight by improving potassium (K) absorption, which is essential for plant growth. Studies indicate that FMA application can enhance the dry bulb weight per plot by up to 19.5% compared to non-inoculated plants (Rahman et al., 2019). The application of FMA at a rate of 10 g/plant has been reported to increase bulb weight by 21.53% (Asad et al., 2023). This beneficial effect is attributed to the ability of FMA to improve soil potassium availability, thereby enhancing photosynthetic efficiency and the translocation of assimilates to the bulbs, ultimately improving the yield and quality of shallots.

Table 3. Effect of FMA dosage on shallot yield

Treatment	Observation Variable							
	BN		BD (mm)		BFW (g)		HI (%)	
T0	8.83	a	17.49	a	38.80	ab	0.16	a
T1	7.00	a	14.84	a	23.25	b	0.19	a
T2	7.75	a	17.26	a	35.71	ab	0.14	a
T3	7.88	a	16.21	a	21.64	b	0.16	a
T4	7.16	a	18.67	a	50.65	a	0.13	a

Description: T0 = (0 FMA inoculant treatment/plant), T2 = (10 g FMA inoculant/plant), T3 = (20 g FMA inoculant/plant), T3 = (30 g FMA inoculant/plant), T4 = (40 g FMA inoculant/plant), BN = Bulb number, BD = Bulb diameter (mm), BFW = Bulb fresh weight (g), HI = Harvest index (%).

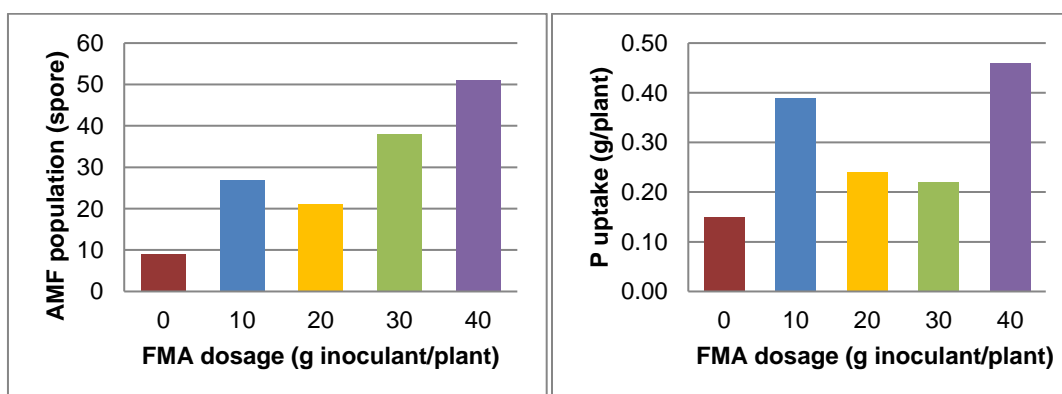


Fig. 3. Effect of FMA dose on FMA population and plant P uptake

In this study, the experimental were initially fertilized with urea (250 kg/ha), KCl (100 kg/ha), and SP36 (37.5 kg/ha), while baseline soil analysis indicated acidic conditions (pH 4.37) with the following characteristics: total nitrogen (0.21%), available phosphorus (4.54 ppm), exchangeable potassium (0.26 me/100g), high organic carbon content (3.57%), and elevated exchangeable aluminum levels (1.67 me/100g).

Yunedi and Perdana (2023) stated that increasing the dose of FMA strengthens the interaction with plant roots, thereby increasing phosphorus absorption. This interaction plays an important role in the growth and quality of shallot bulbs (Arisma et al., 2024). Indriani et al. (2011) reported that the dose of FMA infection in roots affects the efficiency of nutrient absorption by plants. Hyphae and spores in the soil increase the opportunity for FMA symbiosis with plants, supporting overall plant growth. In addition, FMA colonization in roots through hyphae increases the efficiency of nutrient and water absorption for plants (Baptisa et al., 2011; Xie et al., 2022).

FMA enhances nutrient absorption through external hyphae that expand the root absorption area and penetrate deeper into soil pores. It increases phosphorus uptake by improving root affinity and reducing the depletion zone. Additionally, FMA modifies rhizosphere chemistry by releasing organic acids and increasing phosphatase enzyme activity, which increases phosphorus availability. It also stimulates phytohormone production, promoting root structural changes that improve overall nutrient absorption (Orcutt & Nilsen, 2000).

FMA (Fungi Mycorrhizal Arbuscular) did not significantly influence several growth variables due to the initial application of synthetic fertilizers, including urea, SP-36, and KCl. High doses of nitrogen fertilizer can inhibit FMA development, limiting its symbiotic function (Puspitasari et al., 2012). Excessive P and N plots levels reduce spore production, thereby restricting FMA colonization as root surface area for symbiosis decreases (Nurhandayani et al., 2013).

The performance of FMA on plant growth is influenced by the availability of nutrients such as nitrogen (N) and phosphorus (P) in the planting medium. Conditions lacking these nutrients will increase the symbiotic relationship between FMA and plants and vice versa in excess nutrients or fertile soil (Morgan et al., 2005). FMA tends to

work more effectively on soils with low fertility levels, such as nutrient-poor, critical, or marginal soils, than fertile soils (Tamin & Puri, 2020). In addition, FMA activity is largely determined by the isolate's effectiveness, the media's nutrient status, and the level of plant dependence on mycorrhiza. Environmental factors such as soil pH, moisture, rainfall, organic C content, and NPK nutrient levels also affect mycorrhizal activity (Saputra & Lovadi, 2015).

4. CONCLUSION

The application of Fungi Mycorrhizal Arbuscular (FMA) significantly influenced shallot growth and yield, particularly fresh and dry shoot weight and fresh onion bulb weight. At a dose of 40 g inoculant /plant, FMA can increase fresh and dry shoots and bulb weight by 24.83%, 2.51%, and 50.65%, respectively, compared to without FMA application.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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