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Application of Arbuscular Mycorrhiza and Organic Fertilizer on the Growth and Yield of Marigold (*Tagetes Erecta* L.)

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Abstract
This study aims to determine the effect of the application of arbuscular mycorrhizal fungi and solid organic fertilizer doses on the growth and yield of marigold plants (Tagetes erecta L.). This research was conducted at the experimental field of the Agrotechnology Study Program, Faculty of Agriculture, Warmadewa University. The study used a Randomized Block Design (RBD) consisting of two factors arranged factorially. The first factor was the arbuscular mycorrhizal fungi dose, consisting of three levels: M1 = 10 g plant⁻¹, M2 = 15 g plant⁻¹, M3 = 20 g plant⁻¹. The second factor was the solid organic fertilizer dose, also consisting of three levels: O1 = 10 tons ha⁻¹, O2 = 20 tons ha⁻¹, O3 = 30 tons ha⁻¹. The results showed that the interaction between arbuscular mycorrhizal fungi and solid organic fertilizer had a significant effect on plant height, number of flowers, and flowering time. The highest number of flowers was obtained in the treatment of 20 g arbuscular mycorrhizal fungi and 30 tons ha⁻¹ solid organic fertilizer (M3O3), with an average of 10.83 florets, while the fastest flowering time was recorded at 46.83 days. Meanwhile, the arbuscular mycorrhizal fungi factor alone significantly affected the number of leaves, number of branches, flower diameter, root length, and root weight. The solid organic fertilizer factor significantly affected the number of leaves, flowering time, and root weight. The combination of 20 g arbuscular mycorrhizal fungi and 30 tons ha⁻¹ solid organic fertilizer proved most effective in supporting growth and flower development in marigold cultivation.

Keyword: *Mycorrhizal; Solid Organic Fertilizer; Tagetes Erecta L*

1. Introduction

Marigold plants (*Tagetes erecta* L.) are annual ornamental plants of the Asteraceae family that are widely cultivated in Indonesia. This plant is native to North America and has spread to various tropical regions, including Indonesia. Marigold is known as gumitir in Bali, and has wide potential, both as a natural dye, ornamental plant, and biological agent in pest control due to its allelopathic compounds [1]. Marigold flowers also have pharmacological properties as antioxidants, antibacterials, anti-inflammatories, and anticarcinogens [2]. Bali is one of the main centers of marigold production in Indonesia. Areas such as Peplantg, Baturiti, and Kintamani Districts are known as the main marigold-producing areas. The market needs of this crop reach 8 tons per day, and the economic value ranges from 100-200 billion rupiah per year [3].

High market demand cannot be balanced with sufficient production, so marigold prices are often unstable. The main obstacle in marigold cultivation is suboptimal soil quality, especially in land with low fertility levels. Increasing productivity in agricultural conditions now will not be far from the use of inorganic fertilizers; this has been done from year to year in relatively massive amounts [4]. Uncontrolled use of inorganic fertilizers can damage soil structure and decrease natural fertility [5]. Therefore, a more environmentally friendly alternative is needed, one of which is through the use of solid organic fertilizers.

Solid organic fertilizers are able to improve the physical, chemical, and biological properties of the soil and gradually increase the availability of nutrients [6]. The results of a study on the effect of organic fertilizers and the application of fish amino acids on the vegetative growth and dry matter production of African marigold plants (Tagetes erecta l.) showed that the application of 30 tons ha^{-1} of organic fertilizer on marigold plants gave the best results on plant height, number of leaves, and number of branches [7]. One type of solid organic fertilizer on the market is lemek cider solid organic fertilizer, which is a fertilizer with a combination of janur compost, cow manure, and chicken. This fertilizer contains C-Organic 21.06%, N 1.31%, P_2O_5 2.53%, and k_2O 1.59%

Biofertilizers can also contribute significantly to the fertilization process of agricultural land, increasing the efficiency of nutrient absorption [8]. Arbuscular mycorrhizal fungi (AMF) are a type of biological fertilizer that can symbiosis with plant roots and expand the absorption surface so that the absorption of water and nutrients, especially phosphorus, becomes more efficient [9]. AMF can be symbiotic with most (97%) plant families, such as food crops, horticulture, forestry, and plantations [10]. An optimal dose of mycorrhizal fungi is proven to be able to increase vegetative growth of plants, where an increase in AMF dose is in line with increased plant growth [11]. Research on the cultivation of marigold flowers through fertilization efficiency found that the combination of AMF, a dose of 20 g/plant with compost, gave the best results on various marigold agronomic parameters, such as plant height, stem diameter, number, and diameter of flowers. The combination of using mycorrhiza and solid organic fertilizers can be to reduce dependence on chemical fertilizers, improve production efficiency, and maintain the quality of soil ecosystems [12].

2. Materials and Methods

This research was conducted in a garden soil in Serongga Village, Gianyar District, Gianyar Regency, Bali Province, with an altitude of 78 meters above sea level. This research lasted for 2 months from February 1 - March 31, 2025. The materials used in this study are garuda marigold seeds, dense organic fertilizer lemek sari, and mycorrhizal arbuscula fungi. The tools used in this study are hoes, earthen forks, electric scales, labels, pesticides, ajir, raffia rope, scissors, plaster, and plant prop.

This study is a factorial experiment with a basic design of a Randomized Block Design (RBD) with 2 factors tested. The first factor is to use Arbuscular Mycorrhizal Fungi (AM), consisting of 3 levels: M_1 = 10 g per plant, M_2 = 15 g per plant, M_3 = 20 g per plant. The second factor is the use of Solid Organic Fertilizer (O): O_1 10 tons ha^{-1}, O_2 20 tons ha^{-1}, and O_3 30 tons ha^{-1}. All observations were carried out at 56 days after transplanting.

The variables observed included vegetative growth, reproductive traits, and root characteristics. Vegetative growth was assessed through plant height (cm), number of leaves per plant, number of branches per plant, and stem diameter (mm). Reproductive traits were evaluated by recording the age at flowering initiation (days), flower diameter (mm), number of flowers per plant (florets), and fresh flower weight (g). Root characteristics were measured in terms of root length (cm) and root weight (g).

3. Results and Discussion

3.1 Result

Based on statistical analysis, arbuscular mycorrhizal (M), solid organic fertilizer (O), and their interaction (M × O) showed varying effects on the observed variables (Table 1). The highest plant height was recorded at a mycorrhizal dose of 20 g $plant^{-1}$ (M3), reaching 125.69 cm, while the lowest was at 10 g $plant^{-1}$ (M1), with 123.89 cm. Solid organic fertilizer at 30 tons ha^{-1} (O3) produced the tallest plants (128.17 cm), while 10 tons ha^{-1} (O1) resulted in the shortest (120.00 cm). Leaf number was highest in M3 (1058.25 leaves) and lowest in M1 (952.17 leaves). For organic fertilizer, O2 (20 tons ha^{-1}) produced the highest leaf number (1058.47 leaves), while O3 (30 tons ha^{-1}) produced the lowest (966.50 leaves) (Table 2).

Table 1. Significance of the influence of mycorrhizal (M) and solid organic fertilizer (O) doses and their interactions on all observed variables.

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No	Variable	Treatment		
		M	O	Interaction (MxO)
1	Plant Height (cm)	ns	ns	*
2	Number of Leaves (sheets)	*	*	ns
3	Number of Branches (fruit)	**	ns	ns
4	Rod Diameter (mm)	ns	ns	ns
5	Flowering Time (DAT)	ns	**	**
6	Total Interest (floret)	ns	ns	*
7	Flower Diameter (mm)	**	ns	ns
8	Fresh Weight Flower (g)	ns	ns	ns
9	Root Length (cm)	**	ns	ns
10	Fresh Weight of Roots (g)	**	**	ns

Information: ns = no significant ($P \geq 0.05$); * = significant ($P < 0.05$); ** = very significant ($P < 0.01$)

The branch number was highest in M3 (24.19 branches) and lowest in M1 (22.69 branches). Stem diameter showed no significant differences, although the largest values were observed in M1 (19.58 mm) and O2 (19.66 mm). Flowering occurred earliest in M3 (47.25 days) and O3 (46.67 days), while the latest flowering was observed in M1 (48.08 days) and O1 (48.00 days) (Table 2).

Table 2. Results of parameter analysis with 5 % LSD level test

Treatment	Plant Height (cm)	Number of Leaves (sheets)	Number of Branches (fruit)	Rod Diameter (mm)	Flowering Age (DAT)
Mycorrhizal (M)					
M_1 (10 g plant^{-1})	123.89 a	952.17 b	22.69 b	19.58 a	48.08 a
M_2 (15 g plant^{-1})	123.94 a	990.86 ab	23.67 a	18.31 a	47.61 a
M_3 (20 g plant^{-1})	125.69 a	1058.25 a	24.19 a	18.81 a	47.25 a
LSD 5%	5.18	69.81	0.78	1.80	0.96
Solid Organic Fertilizer (O)					
O_1 (10 tons ha^{-1})	120.00 b	976.31 b	23.08 b	18.36 a	48,00 a
O_2 (20 tons ha^{-1})	125.36 a	1058.47 a	23.53 a	19.66 a	48.28 a
O_3 (30 tons ha^{-1})	128.17 a	966.50 b	23.94 a	18.68 a	46.67 b
LSD 5%	5.18	69.81	0.78	1.80	0.96

Generative parameters showed that flower number was highest in M3 (9.25 florets) and O3 (9.67 florets), while lowest in M1 (8.00 florets) and O1 (7.56 florets). Flower diameter was largest in M3 (64.59 mm) and O2 (61.05 mm), while smallest in M1 (58.13 mm) and O3 (59.30 mm). Fresh flower weight was highest in M3 (192.83 g) and O3 (192.47 g), while lowest in M2 (154.11 g) and O1 (160.97 g).

Root observations showed that root length was longest in M3 (23.75 cm) and shortest in M1 (15.97 cm). O2 and O3 produced equal root lengths (19.83 cm), higher than O1 (19.03 cm). Fresh root weight was highest in M3 (26.25 g) and lowest in M1 and M2 (18.56 g). O3 produced the highest root weight (22.31 g), while O1 produced the lowest (19.67 g) (Table 3).

Table 3. Results of parameter analysis with 5 % LSD level test

Treatment	Number of Flowers (floret)	Flower Diameter (mm)	Fresh Weight Flower (g)	Root Length (cm)	Root Weight (g)
Mycorrhizal (M)					
M1 (10 g plant^{-1})	8.00 a	58.13 b	188.11 a	15.97 c	18.56 b

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M2 (15 g plant^{-1})	8.08 a	58.36 b	154.11 a	18.97 b	18.56 b
M3 (20 g plant^{-1})	9.25 a	64.59 a	192.83 a	23.75 a	26.25 a
LSD 5%	1.56	4.29	50.43	2.66	2.14
Solid Organic Fertilizer (O)					
O1 (10 tons ha^{-1})	7.56 b	60.73 a	160.97 a	19.03 a	19.67 b
O2 (20 tons ha^{-1})	8.11 a	61.05 a	181.61 a	19.83 a	21.39 a
O3 (30 tons ha^{-1})	9.67 a	59.30 a	192.47 a	19.83 a	22.31 a
LSD 5%	1.56	4.29	50.43	2.66	2.14

3.1 Discussion

The effectiveness of mycorrhizal infection was evident from increased root length and fresh root weight. A dose of 20 g plant^{-1} (M3) increased root length by 45% and root weight by 41% compared to 10 g plant^{-1} (M1). Mycorrhizae form external hyphal networks that extend through root hairs, expanding the absorption area and enhancing nutrient uptake [13]. Solid organic fertilizer provides essential nutrients and serves as a medium for beneficial microorganisms. Its nutrient composition—N (1.31%), P_2O_5 (2.53%), K_2O (1.73%), and organic C (21.06%)—plays a key role in supporting vegetative growth and flower formation. Phosphorus promotes the development of the delicate root system, strengthens flowering, and improves nutrient absorption efficiency. Meanwhile, potassium strengthens plant resistance to drought stress and disease, improves the quality of plant tissues, and improves carbohydrate production [14]. The nutrients provided by organic fertilizers can be utilized efficiently due to the role of mycorrhizae in expanding root tissue. The efficiency of nutrient absorption by the roots increases the supply of nutrients to the meristematic tissues of the shoots and leaves, thereby supporting the process of cell division and stimulating vegetative growth in the form of increased leaf count and plant height [15].

The interaction between M × O significantly affected flower number and plant height, and had a highly significant effect on flowering time. The highest flower number was obtained in the M3O3 treatment (10.83 florets), while the fastest flowering occurred in M2O3 (45.42 days). This indicates that nutrient balance created through the combination of mycorrhizae and solid organic fertilizer contributed to the optimal generative phase of marigold plants. Nitrogen content in the soil is relatively low, but it is suspected that the presence of mycorrhiza and solid organic fertilizers in the soil helps increase the availability of nitrogen nutrients that stimulate the growth of marigold plants. The results of the study on the effect of arbuscular mycorrhizal and organic fertilizers on soil chemical properties found that the application of mycorrhizae had a very pronounced effect on N-total in the soil compared to without mycorrhizae. Mycorrhizae can increase the activity of soil microorganisms in the process of decomposition as well as mineralization of organic matter, so that nitrogen bound in organic matter decomposes more quickly in an inorganic form that can be absorbed by plants [16]. Research on the effect of the application of organic fertilizers and inorganic fertilizers on the absorption of N, P, and K by corn plants found that the addition of organic fertilizers had a real effect on N absorption and had a very real effect on P absorption [17]. The condition of nutrient balance created through the combination of mycorrhizal and solid organic fertilizers is suspected to have contributed to the achievement of the optimal generative phase of plants.

The application of arbuscular mycorrhizal fertilizer had a highly significant effect on the flower diameter of marigold plants, whereas solid organic fertilizer showed no significant effect, and no interaction was observed between the two factors. The largest flower diameter was obtained in the M3O3 treatment, measuring 65.97 mm. Mycorrhizae penetrate plant roots and enhance the absorption of nutrients such as N, P, K, Zn, Co, S, and Mo from the soil, thereby increasing plant resistance to drought stress [18]. Enhanced phosphorus uptake due to mycorrhizal colonization has been shown to contribute to flower formation in marigolds. Phosphorus plays a critical role in supporting metabolic activity in apical meristem tissue, which is the central site of cell growth and differentiation [19]. The lack of a significant effect from solid organic fertilizer on flower diameter is likely due to sufficient soil nutrient levels, particularly phosphorus and potassium, which are essential for flowering.

The combined application of arbuscular mycorrhizal and solid organic fertilizers influenced average flowering time. The fastest flowering was observed in the interaction of 20 g plant^{-1} mycorrhizal fertilizer with 30 tons ha^{-1} solid organic fertilizer (M3O3), resulting in 46.83 days. Simultaneous increases in phosphorus and nitrogen availability can accelerate flower meristem differentiation. Research on the effects of organic fertilizers and plant growth-promoting microbes on the growth, flowering, and oleanolic acid content of Calendula officinalis found that the interaction between mycorrhizal fungi and bacteria significantly enhanced the effects of biofertilizers on plant growth, flowering, flower production, and carotenoid content in marigolds [20]. These findings highlight the importance of integrating mycorrhizal biofertilizers with solid organic fertilizers in sustainable cultivation systems. The combination not only enhances vegetative growth but also accelerates the generative phase, making it an effective strategy to improve marigold productivity and flower quality.

4. Conclusion

The application of arbuscular mycorrhizal biofertilizer had a highly significant effect on branch number, flower diameter, root length, and fresh root weight, and a significant effect on leaf number. A dose of 20 g plant^{-1} (M3) produced the largest flower diameter of 64.59 mm, representing an 11.1% increase compared to 10 g plant^{-1} (M1).

Solid organic fertilizer significantly affected leaf number and had a highly significant effect on flowering time and fresh root weight. A dose of 30 tons ha^{-1} (O3) produced the highest leaf number (1058.25 leaves), representing a 14.3% increase compared to 10 tons ha^{-1} (O1), which yielded 925.17 leaves.

The interaction between mycorrhizal and solid organic fertilizer doses significantly affected flower number and plant height, and had a highly significant effect on flowering time. The M2O3 treatment resulted in the fastest flowering, with an average of 45.42 days. This indicates that the combination of mycorrhizae and solid organic fertilizer creates a nutrient balance that optimally supports both vegetative and generative phases of marigold plants.

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