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Growth and yield response of shallots to NPK, NK, and humic acid under different mycorrhiza application

Abstract. One strategy to increase shallot production is the utilization of microorganisms in the soil, such as arbuscular mycorrhizal fungi (AMF), which is applied together with fertilizer. This research aimed to investigate the effects of different nutrient inputs and mycorrhizal association on the growth and yield of shallots. This study used a split-plot design with three replications as blocks. The main plot included four treatments: no nutrient inputs, NPK fertilizer, NK fertilizer, and humic acid, while the subplot involved the mycorrhiza application (with or without). The measured variables included growth (plant height and number of leaves) and yield (fresh weight and number of bulbs per plant). The results showed no interaction between treatments for any growth or yield parameters. Application of humic acid significantly improved shallot development and yield, producing the highest results compared to other fertilizer types. Mycorrhizal inoculation enhanced plant height and boosted bulb weight per plant. The application of humic substances has been proven to increase 27.82%, while AMF enhanced 12.9 % weight bulb of shallots. Hence, humic substances have the potential to enhance the shallot with or without AMF application.

Keywords: Arbuscular mycorrhizal fungi · Mycorrhizal inoculation · Humic substances · Shallot bulb yield

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Introduction

Shallot is one of the horticulture products, used daily as a spice in cuisine or as a traditional medicine. Shallot bulbs contain protein, carbohydrates, fat, minerals, vitamins, and flavonoids (Moreno-rojas et al., 2018). In 2022, the cultivation of shallots in Indonesia covered an area of 122,126 hectares, resulting in a total national production of 1,229,184 tons, which translates to a national productivity of 10.05 tons per hectare. However, shallot productivity has been fluctuating for the last 10 years (BPS, 2022). Meanwhile, the annual demand for shallots is expected to rise to meet the increased production demand. Therefore, it is necessary to improve production to meet the consumers' needs.

One reason for constraints in shallot production is that large farmers use vegetative propagation methods using bulbs. This method has several weaknesses, including the risk of spreading pests and diseases through the bulbs. Vegetative propagation via bulbs causes this issue, as there is no cycle to eliminate pests and pathogens.

Farmers often use synthetic fertilizers such as urea, SP-36, and KCl as nitrogen (N), phosphorus (P), and potassium (K) sources for plants to achieve maximum results. Using inappropriate synthetic fertilizers can affect nutrient absorption by plants, which can lower harvest yields (Liu et al., 2021). In addition, excessive use of NPK can lead to environmental pollution, endanger health, disrupt ecosystem balance, and harm community-supporting biotic production plants (Savci, 2012). One way to improve shallot production is through the utilization of biological fertilizers. Biological fertilizers consist of materials derived from microorganisms that help increase nutrient availability or stimulate plant growth, including vegetables (Adler et al., 2022). Furthermore, the application of biological fertilizers can also reduce pest and pathogen attacks through various mechanisms, such as enhancing microbial activity in the soil, the presence of microbial metabolites, enzyme activity in the soil, and stimulating plant hormone production (Dinesh et al., 2013). A range of microorganisms used as biological fertilizers can help meet essential nutritional needs such as N, P and K.

One of the microorganisms that plays a role as a solvent for phosphorus available to plants is arbuscular mycorrhizal fungi (AMF). Application of AMF in shallots has been proven to increase growth and nutrient absorption efficiency. Research by (Laila et al., 2019) reported that AMF application increased the growth and yield of shallots. Meanwhile, previous study by Warman et al., (2022) showed that the combination of mycorrhiza and organic fertilizer improves crop yield.

One factor influencing colonization by mycorrhiza is the type of nutrient input. Using inorganic fertilizers at appropriate rates can enhance the potential for establishing a symbiotic relationship, whereas organic fertilizers that release nutrients naturally and gradually can support the sustainability of this symbiosis. Mycorrhiza in plants given organic materials, such as humic acid, are believed to improve soil quality, increase soil nutrient content, such as phosphorus, organic materials, and boost crop production. The combination of AMF and humic acid fertilization has been shown to increase growth and tolerance in some crops, but there are few reports on shallots. So, the specific interaction between soil nutrient input types (e.g., NPK, NK, and humic acid) and AMF inoculation in shallots needs to be studied. Therefore, exploring various combinations of AMF with different soil amendments is crucial to identify the optimal synergy for increasing plant productivity while reducing dependence on chemical fertilizers in shallot cultivation.

Materials and Methods

Time and Place Experiment. The study was conducted in Gedung Baya Village, Kalitimbang Subdistrict, District Cibeber, Cilegon City, from May to July 2024, at an altitude of 553 m above sea level. The chemical properties of the soil used are shown in Table 1. The average temperature during May to July fluctuated between 26.1 °C and 29.4°C, while the average humidity ranged from 75% to 97%.

Table 1. Characteristics of soil media used for research

Component	
Chemical Properties	
pH (H_2O)	6.5
KCl	5.7
C-organic (%)	1.08
N Total (%)	0.10
C/N Ratio	11
P_2O_5 (mg /kg)	225.64
K_2O available (mg/kg)	3.08

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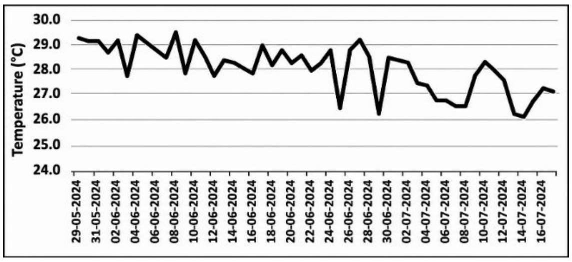

Figure 1. Graph of average temperature (°C) during the study period from May to July 2024

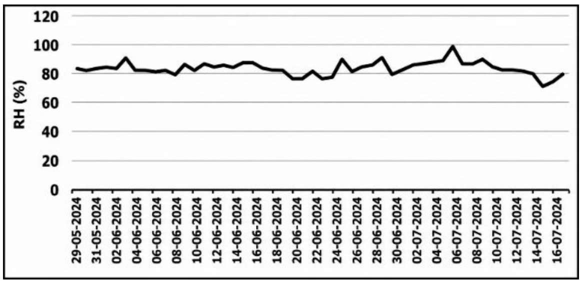

Figure 2. Graph of average relative humidity (%) during the study period from May to July 2024

Materials. Tools used included a hoe, trowel, bucket, plastic, labels, a hand sprayer, and analytical scales. Materials required are seed bulbs of the Bima Brebes variety, soil, urea, TSP, KCl, humic acid, fungicides, and herbicides.

Design Experiment. The study laid out a split-plot design with three blocks as replications. The main plot involved four nutrient input treatments: no nutrient inputs (P0), NPK (P1), NK (P2), and humic acid (P3). The sub-plot included applications of mycorrhiza (M1) and no mycorrhiza application (M0). A total of 24 experimental units were obtained from the treatments. Each experiment plot consisted of 16 plants with 3 sample plants for observation.

Procedure. The land designated for planting has been previously cleared of weeds and other plant remains. Then, raised beds were made with a depth of 30 cm. These raised beds are constructed as high beds, 30 cm in height; the surface beds were loosened and leveled. Planting was done in main plots measuring (2 × 1 m), while the subplots measure (1 × 1 m), with a spacing of 20 cm between plots and blocks. Shallots were planted with a spacing of (20 × 20 cm). Watering was performed daily until the field reached capacity. Fertilizer application followed the specified treatments. In the NPK treatment, fertilizer was applied as a single dose at an N:P:K ratio of 300:100:300 kg.ha^{-1}, using urea, SP-36, and KCl. Urea fertilizer was applied three times, at 2 weeks after planting (WAP), 3 WAP, and 5 WAP. SP-36 and KCl were applied at 2 WAP. The NK treatment involved a combined N and K rate of 300:300 kg.ha^{-1}, using urea and KCl. Urea fertilizer was applied at 2, 3, and 5 WAP, while KCl was applied at 2 WAP. Humic acid fertilizer was applied in powder form at a dose of 200 kg·ha^{-1} two weeks before planting, without adding NPK fertilizer. The absence of fertilizer application means that no treatments were applied. The mycorrhiza treatment was applied one week prior to planting, mixing with soil, using the brand "MycoGrow", at a dose of 10 g per plant. MycoGrow contains 33 spores/g, 300 active propagules/g, and five species of endomycorrhiza on a zeolite medium.

Parameters Observation. Growth parameters included plant height (cm) and the number of leaves (strands) for 3 plant samples per unit, which were measured weekly. The yield parameters consisted of the weight of bulbs per plant (g/plant) and the number of bulbs per plant, at harvest or 56 days after planting.

Data analysis. All observations were analyzed using analysis of variance (ANOVA) for a split-plot design at a 95% confidence level (α = 0.05). The model included main plot effects, subplot effects, and their interaction. When significant differences were detected, mean separation was performed using Duncan's Multiple Range Test (DMRT) at α = 0.05.

Results and Discussion

This research was conducted from May to June 2024, with temperatures ranging from 26.2 to 29.5 °C (Fig. 1) and relative humidity ranging from 79 to 100% (Fig. 2), indicating that the temperature and humidity are suitable for shallot growing. The soil traits showed that N content was low, P content was high, K was low, organic matter was ideal or moderate, and C/N was optimal (Table 1). It was also indicated that the soil did not require P input, as it was sufficient.

Research results showed that there was no interaction between both factors for all growth and yield parameters. It indicated that soil amendments have different effects on plant height at 1, 2, and 4 WAP. Humic acid could enhance plant height during the initial vegetative stage, reaching 8.25 cm at 1 WAP and 22.92 cm at 2 WAP. The increase continued at the 4 WAP with the plant height reaching 33.92 cm (Table 2). This occurs because the use of humic acid can stimulate the rapid increase in plant height. In plants that received no fertilizer, height was shorter due to delayed sprout emergence, which slows down growth compared to other treatments. However, in the final observation, there is no significant difference.

Humic acid is a naturally occurring material used to repair land, which is produced through the humus extraction process with a high dose (Allahkarami et al., 2025). As an organic fertilizer, humic acid can enhance the physical, chemical, and biological properties of soil (Ampong et al., 2022), including increasing cation exchange capacity (CEC), which enables the land to retain nutrients more effectively, making the soil looser and reducing acidity levels. This occurs because humic acid can improve soil properties by enhancing its chemical and physical state, binding aluminum, which causes acidity, and forming compounds that are difficult to decompose. The content of humic acid includes Sulphur (S), P, oxides of aluminum and iron, sodium (Na), potassium sulfate, magnesium, and a small amount of manganese. Previous studies showed that humic acid improved vegetative growth, including plant height (Rasouli et al., 2022).

Mycorrhiza application had no significant effect on early plant height growth, but it did affect the final observed height. The plant treated with mycorrhiza reached a height of 35.78 cm in the 6 WAP (Table 2). Other research also confirms that applying mycorrhiza can promote plant height growth. AMF absorbs NO_3^- and NH_4^+ through external hyphae, converting them into arginine outside the hyphae, then transferring it to internal hyphae. In the roots, arginine is broken down into ammonium, which plants directly assimilate, thereby increasing nitrogen availability (Bücking and Kafle, 2015). Nitrogen, an essential macronutrient, is readily soluble and easily available to plants, allowing direct root absorption. This element is crucial for vegetative growth, especially for increasing plant height and leaf quantity.

Applying various fertilizers affects shallot leaf growth between 2 and 5 WAP. The highest number of leaves was shown at 2 to 5 WAP when humic acid was applied. The observation results show that the number of leaves was 9.50 at 2 WAP, increasing to 24.33 at 5 WAP. However, by the end of the observation, different soil amendments did not produce varying results in leaf number. The leaf count ranges from 21.44 to 25.06 leaves per plant (Table 3). Humic acid is known to enhance nitrogen absorption, thereby potentially increasing the number of leaves (Ma et al., 2024). This is like other studies that reported humic acid enhanced the number of leaves on crops such as gladiolus (Ahmad et al., 2013) and beans (Qian et al., 2015).

Application of mycorrhiza did not affect the growth or the number of leaves observed over time. The number of leaves in shallots under various mycorrhiza treatments at the end of observation ranged from 24.00 to 24.17 strands (Table 3). Mycorrhizae increased plant height because the external hyphae expand water and nutrient absorption, causing the stem and tissues to elongate more quickly. However, leaf formation is more influenced by genetic factors, so mycorrhizae do not always increase the number of leaves, even when plant height increases.

Table 2. Shallot plant height (cm) in various treatments

Treatment	Week After Planting (WAP)					
	1	2	3	4	5	6
Types of Fertilizer (F)						
Without Fertilizer	6.00 b	20.67 b	28.97 a	31.97 b	33.61 a	35.08 a
NPK	6.83 ab	21.02 ab	29.06 a	32.14 ab	33.00 a	34.69 a
NK	6.67 ab	20.72 b	28.97 a	33.00 ab	33.69 a	34.77 a
Humic acid	8.25 a	22.92 a	30.44 a	33.92 a	34.47 a	35.27 a
AMF (M)						
0 g/plant	6.37 m	20.65 m	28.96 m	32.44 m	33.35 m	34.13 n
10 g/plant	7.50 m	22.01 m	29.76 m	33.06 m	34.04 m	35.78 m
Interaction (F×M)	ns	ns	ns	ns	ns	Ns

Notes: ns = non-significant; Numbers within the same columnn followed by different letters indicate significant differences according to Duncan Multiple Range Test at $p \leq 0.05$.

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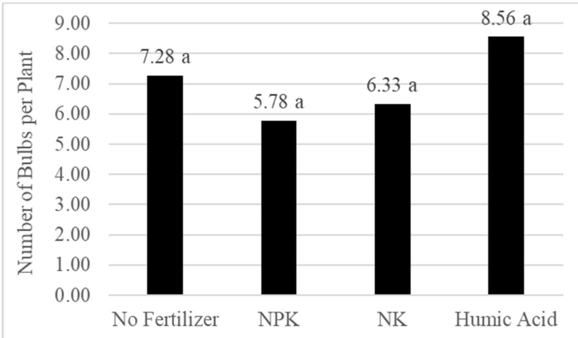
Table 3. Number of leaves (blades) of shallot on various treatments

Treatment	Weeks After Planting (WAP)					
	1	2	3	4	5	6
Types of Fertilizer (F)						
Without Fertilizer	5.27 a	8.39 b	15.44 ab	19.11 bc	21.94 ab	23.89 a
NPK	4.83 a	7.56 b	14.44 b	16.94 c	20.39 b	21.44 a
NK	5.45 a	8.22 b	17.94 ab	21.94 ab	24.61 ab	25.94 a
Humic Acid	7.17 a	9.50 a	19.50 a	22.17 a	24.33 a	25.06 a
AMF (M)						
0 g/plant	5.69 m	8.42 m	16.94 m	20.39 m	22.92 m	24.17 m
10 g/plant	5.67 m	8.42 m	16.72 m	19.69 m	22.72 m	24.00 m
Interaction (F×M)	ns	ns	ns	ns	ns	ns

Notes: ns = non-significant; Numbers within the same columnn followed by different letters indicate significant differences according to Duncan Multiple Range Test at $p \leq 0.05$.

This research showed that variation in fertilizers and humic acid did not affect the number of bulbs per plant, with an average of 5.78 to 8.56 bulbs per plant. Still, applying mycorrhizae produced results that were not significantly different from those without application, with the number of bulbs ranging from 6.81 to 7.17 per plant (Figure 3). Humic acid, one of the kinds of soil amendments that contribute to increasing soil health through improving soil properties and microbial activities (Li et al., 2019), while mycorrhiza application can increase the availability of the element P (Thioub et al., 2019). Phosphorus nutrients in mycorrhizal fertilizers play a crucial role as a structural component in DNA molecules, in energy transfer through ATP, and in regulating phosphate chemistry synthesis, all of which influence plant growth and development (Sbrana et al., 2022). This result indicated that the P soil content is sufficient for the number of shallot bulbs formed. It may indicate that biofertilizer application did not increase some of crop growth and yield parameters because soil nutrients were already available.

Harvested shallot yields varied across different fertilizers and humic acid treatments. Applying humic acid could increase the weight of bulbs per plant from 21.11 g/plant, compared to without fertilization, to 31.59 g/plant (Fig. 4). Humic acid also provides nutrients plants need, although in small amounts. This improvement may be due to humic acid's role in improving the availability of essential macro and micronutrients for photosynthesis and biomass accumulation. Humic substances can also stimulate microbial activity, therefore enhancing nutrient uptake efficiency. These results are similar some research that the crops yield increased after humic acid application (Li et al., 2019).



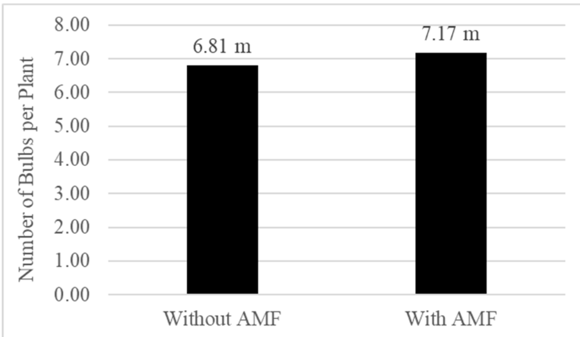
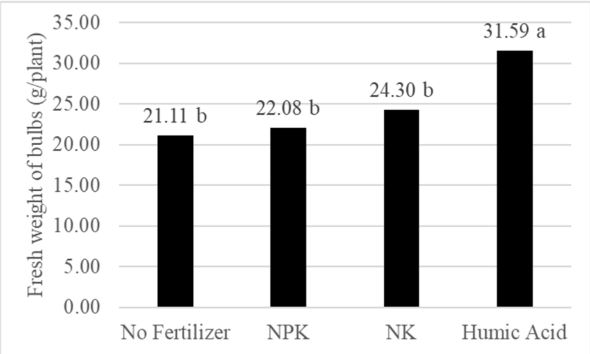


Figure 3. Number of bulbs of shallots on various treatments

Notes: ns = non-significant; Numbers within the same columnn followed by different letters indicate significant differences according to Duncan Multiple Range Test at $p \leq 0.05$.



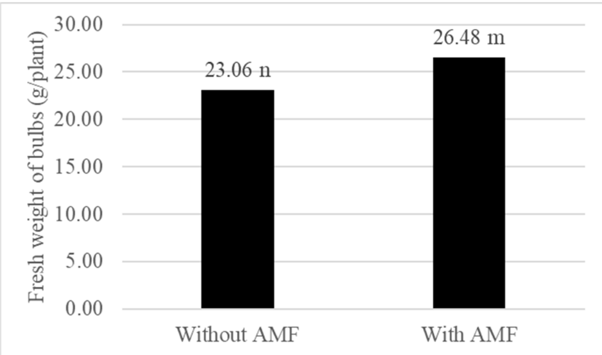


Figure 4. Weights of bulbs of shallot in various treatments

Notes: ns = non-significant; Numbers within the same columnn followed by different letters indicate significant differences according to Duncan Multiple Range Test at $p \leq 0.05$.

Mycorrhiza application could significantly increase shallot bulbs' weight. The shallot that was given mycorrhiza application increased from 23.06 g/plant to 26.48 g/plant (Fig. 4). With proper dosage, mycorrhiza can enhance soil fertility, improve soil properties, and help maintain environmental balance. Other roles of mycorrhiza for plants include facilitating absorption, assimilation, and translocation of nutrients from outside the rhizosphere zone to the plant roots through mycelium (Fall et al., 2022). Based on previous studies, it is well known that mycorrhizae can increase crop yield (Yadav et al., 2023).

Conclusion

Humic acid has the greatest influence on initial vegetative growth and bulb weight, while mycorrhizae increased the maximum plant height and bulb weight. However, there is no significant interaction between the main plot and the subplot on any of the observed parameters. Hence, the use of humic acid and mycorrhizae could become a sustainable strategy to improve shallot productivity while reducing dependence on inorganic fertilizers.

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