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Growth and Yield Responses of Shallots to Fertilizer Regimes and Mycorrhizal Inoculation

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Abstract
The study investigated the combined effects of fertilization and arbuscular mycorrhizal fungi (AMF) inoculation on the growth and yield performance of shallots (Allium cepa var. aggregatum) under pot conditions. A randomized complete block design was employed with two factors: fertilizer type (NPK, NK, humic acid, and no treatment) and AMF dose (0, 5, and 10 g plant^{-1}), each replicated three times. Growth traits, including plant height and leaf number, alongside yield components such as bulb number and bulb weight, were measured and statistically analyzed using ANOVA and Duncan's Multiple Range Test. The results showed that fertilization had a significant effect on growth and yield parameters. NPK consistently promoted the greatest plant height and bulb weight, underscoring the critical role of balanced nutrient availability. NK fertilizer also enhanced bulb formation, while humic acid alone resulted in lower values, indicating its better suitability as a supplementary amendment rather than a primary nutrient source. AMF inoculation demonstrated potential to increase yield traits, with the 10 g per plant dose improving both bulb number and bulb weight, confirming its role in enhancing nutrient uptake efficiency and biomass allocation. Overall, integrating mineral fertilizers—particularly NPK—with AMF inoculation shows strong potential to optimize shallot production while supporting sustainable soil management.

Keywords:
shallot, AMF, fertilization, bulb, agriculture

1. Introduction

Shallots (*Allium ascalonicum* L.) are among the most important horticultural commodities in Indonesia, widely consumed and traded internationally. However, their cultivation typically requires high nutrient inputs. Farmers often depend heavily on chemical fertilizers, which, while effective in the short term, can cause long-term soil degradation and environmental issues [1] [2]. his situation underscores the urgent need to develop fertilization strategies that maintain productivity while ensuring sustainability [3].

One alternative approach is the utilization of arbuscular mycorrhizal fungi (AMF) [4] [5]. These fungi form symbiotic associations with plant roots, helping plants absorb water and nutrients, particularly phosphorus, while also enhancing resilience under suboptimal soil conditions. Numerous studies have demonstrated that inoculating crops with arbuscular mycorrhizal fungi (AMF) can reduce dependence on inorganic fertilizers while simultaneously improving plant performance. Research has shown that AMF application enhances growth and nutrient uptake even when fertilizer input is reduced [6] [7].

For shallots specifically, encouraging results have been reported. A researcher observed that applying arbuscular mycorrhizal fungi (AMF) in combination with organic inputs increased shallot yields by nearly twofold compared to unfertilized controls. [8]. Similarly, a researcher documented that applying 5–10 g of AMF per plant significantly increased root biomass and overall yield in organically managed crop fields [9]. These findings suggest that adjusting AMF inoculation levels can directly influence shallot growth and yield.

Besides AMF, humic acid has also received attention as a soil amendment. This organic compound improves soil aggregation, enhances nutrient availability, and promotes better root development [10]. When applied in combination with mycorrhiza and balanced fertilization, humic acid has been shown to potential increasing the growth and yield of shallots, and soil quality [11] [12].

Despite these advancements, systematic studies that evaluate the interaction between different AMF dosages (including no inoculation) and specific fertilization regimes—namely NPK, NK (without phosphorus), and humic acid—remain limited, especially under controlled pot experiments. Such investigations are essential to determine whether the beneficial effects of AMF can compensate for reduced fertilizer application or synergize with organic amendments like humic acid.

In this context, the present research was designed to investigate how three inoculation levels of AMF (0, 5, and 10 g per plant) interact with three types of fertilization NPK, NK, and humic acid in shaping the growth and yield of shallots under pot culture. It is anticipated that AMF will enhance nutrient uptake efficiency and improve plant performance, particularly when phosphorus supply is limited or when organic amendments are used. Ultimately, the findings are expected to contribute to the development of fertilization practices that are both productive and environmentally responsible.

2. Material and Methods

Plant Material

The experiment was carried out using shallot (*Allium ascalonicum* L.) bulbs of the Bima Brebes variety, which is widely cultivated in Indonesia.

Experimental Design

The study was arranged in a Randomized Complete Block Design (RCBD) with three replications, where each block represented one replication to minimize environmental variation. Two treatment factors were applied: (1) fertilizer type, consisting of NPK, NK, humic acid, and an unfertilized control; and (2) AMF dosage, consisting of 0, 5, and 10 g per plant. This factorial arrangement resulted in 12 treatment combinations, each replicated three times, for a total of 36 experimental units. Each unit consisted of three polybags containing one shallot plant that was maintained under standard cultural practices.

Fertilizers and Soil Amendments

Nutrient management involved both inorganic and organic inputs. The NPK treatment consisted of a combination of urea (46% N), SP-36 (36% P_2O_5), and KCl (60% K_2O). The NK treatment consisted of urea and KCl without phosphorus addition, whereas the organic amendment was provided in the form of humic acid using The Andersons Humic DG & SG. Fertilizers and humic acid were applied at recommended doses and incorporated into the soil at planting. Additional applications of N and K were given according to crop growth stages to maintain nutrient availability. A control treatment with no fertilizer application was included for baseline comparison.

Mycorrhizal Inoculum

The arbuscular mycorrhizal fungi (AMF) inoculum used was the commercial product My Covir, containing a mixture of fungal genera: Glomus sp. (53 spores g^{-1}), Enterospora (52 spores g^{-1}), Gigaspora (28 spores g^{-1}), and Acaulospora (36 spores g^{-1}). The inoculum was applied directly into each planting hole before bulb placement at three dosage levels: 0, 5, and 10 g per plant.

Data Collection

Observations were made on growth and yield parameters. Plant height was measured from the soil surface to the tip of the tallest leaf at 30 and 45 days after planting (DAP). The number of leaves per plant was counted manually. At harvest maturity, and fresh bulb weight was recorded with an analytical balance. Total yield per pot was calculated as the cumulative bulb weight harvested from each unit.

Statistical Analysis

All data collected were subjected to analysis of variance (ANOVA) to evaluate the effects of fertilizer type, AMF dosage, and their interaction. When significant treatment differences were detected, mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at the 5% significance level.

3. Results and Discussion

The current study investigated the effects of different fertilizer types (NPK, NK, humic acid, and a no-fertilizer control) and varying doses of arbuscular mycorrhizal fungi (AMF; 0, 5, and 10 g per plant) on the growth attributes of shallots. The growth parameters measured included plant height and the number of leaves, which are critical indicators of vegetative vigor and potential yield formation in shallots.

3.1 Plant Height

The analysis showed that fertilizer application had a significant effect on shallot plant height. Among the different treatments, plants receiving NPK fertilizer achieved the greatest height (36.12 cm), followed by those treated with NK fertilizer (34.42 cm). The untreated control produced intermediate values (33.74 cm), while the lowest growth was observed with humic acid treatment (31.53 cm). These findings suggest that the availability of a balanced set of macronutrients, particularly phosphorus, is crucial for promoting vegetative development. Phosphorus plays a central role in root growth, ATP-driven energy transfer, and shoot elongation, which explains why NPK consistently outperformed NK and humic acid treatments [13].

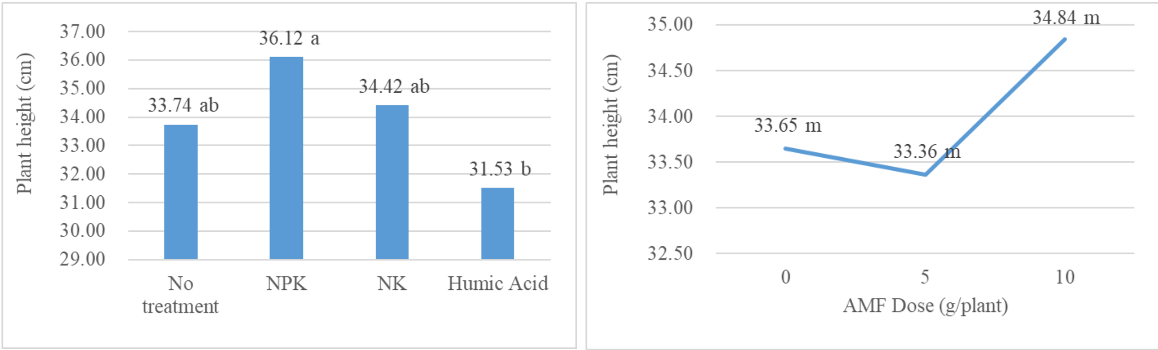

Figure 1

Effect of fertilizer types and arbuscular mycorrhizal fungi (AMF) doses on plant height of shallots under pot conditions. Different letters above the bars indicate significant differences according to Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$.

The relatively weaker performance of NK fertilizer compared with NPK reflects the limitations caused by the absence of phosphorus. Although nitrogen promotes cell division and leaf initiation, and potassium supports osmotic balance and carbohydrate transport, the lack of phosphorus restricts the full expression of growth potential. Similar patterns have been reported in onions, where phosphorus deficiency resulted in shorter leaves and reduced biomass accumulation [14]. Humic acid, when used alone, was not effective in enhancing plant height. While humic substances can stimulate root activity and improve nutrient solubility, their effects are usually complementary to mineral fertilizers rather than substitutive [15].

The addition of arbuscular mycorrhizal fungi (AMF) did not significantly alter plant height. However, a gradual upward trend was evident at higher inoculation levels, with plants at 10 g plant^{-1} showing 34.84 cm compared to 33.65 cm and 33.36 cm in the 0 and 5 g treatments. This tendency is consistent with the known role of AMF in improving nutrient acquisition and water uptake through extended root hyphae [16]. The absence of statistical significance could be due to relatively fertile soil conditions in the experimental medium, which may have reduced the dependence of shallots on mycorrhizal symbiosis. In general, the benefits of AMF are most apparent under nutrient stress or drought conditions [17] [18].

Taken together, these results emphasize that shallot plant height is most strongly driven by mineral nutrient supply, with NPK offering the most balanced support. Nevertheless, the positive tendency at higher AMF doses suggests that integrating AMF with fertilizer strategies could be valuable in more variable or resource-limited field environments.

3.2 Number of Leaves

The analysis demonstrated that fertilizer application significantly affected shallot plant height. Among the treatments, plants receiving NPK fertilizer exhibited the greatest height (36.12 cm), followed by those treated with NK fertilizer (34.42 cm). The untreated control showed intermediate growth (33.74 cm), while the lowest height was observed with humic acid treatment (31.53 cm). These results suggest that the availability of a balanced set of macronutrients, particularly phosphorus, is essential for promoting vegetative development. Phosphorus plays a key role in root growth, ATP-driven energy transfer, and shoot elongation, which explains why NPK consistently outperformed NK and humic acid treatments.

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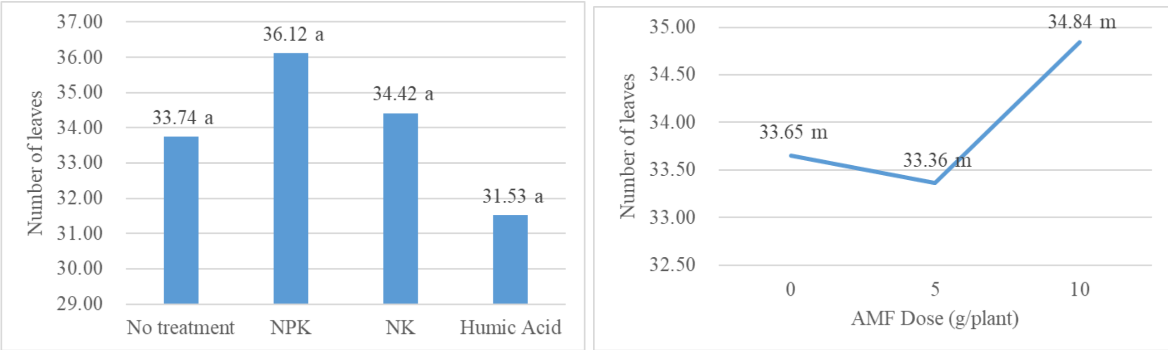

Figure 2
Effect of fertilizer types and arbuscular mycorrhizal fungi (AMF) doses on number of leaves of shallots under pot conditions. Different letters above the bars indicate significant differences according to Duncan's Multiple Range Test (DMRT) at p ≤ 0.05.

Leaf number is often considered a morphological trait that is less plastic compared to other growth parameters, such as plant height or biomass accumulation. Some studies have reported that genetic factors largely determine leaf variation, indicating a stronger genetic influence than environmental effects [19].

Fertilizer trials on crops also showed that the number of leaves remained largely unchanged. This suggests that leaf count may not be a sensitive indicator of treatment response in shallot production.

The absence of significant differences in leaf number in the present study suggests that resource allocation in shallots is prioritized toward bulb development rather than continuous leaf proliferation under favorable nutrient conditions. This finding indicates that the benefits of arbuscular mycorrhizal fungi (AMF) are more pronounced in root and yield-related traits than in aboveground leaf counts.

3.3 Number of Bulbs per Plant

The findings revealed that neither fertilization treatments (NPK, NK, and humic acid) nor arbuscular mycorrhizal fungi (AMF) inoculation had a significant effect on the number of bulbs produced per shallot plant. Although slight numerical differences were observed—such as a higher bulb number in NK-treated plants and at the highest AMF dose—these variations were not statistically significant. This indicates that bulb number is relatively stable and not strongly influenced by short-term soil amendments or microbial inoculation under the experimental conditions.

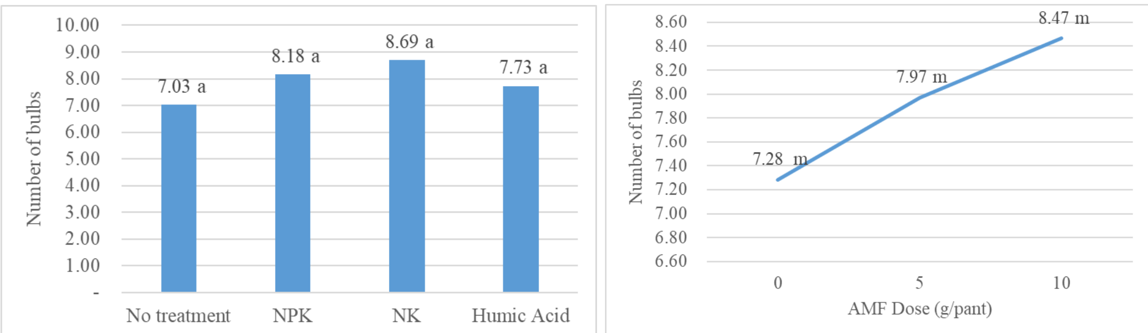

Figure 3
Effect of fertilizer types and arbuscular mycorrhizal fungi (AMF) doses on number of bulbs of shallots under pot conditions. Different letters above the bars indicate significant differences according to Duncan's Multiple Range Test (DMRT) at p ≤ 0.05.

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Bulb initiation and multiplication in shallots may largely governed by genetic factors rather than external inputs. Nutrient availability, particularly nitrogen and potassium, plays an important role in enhancing bulb size and weight [20], but this research showed that it does not always translate into an increase in bulb count. The present results are consistent with findings in onion, where fertilizer treatments improved biomass and bulb diameter [21] [22].

Similarly, the application of AMF did not result in significant improvements in bulb number. AMF are known to enhance phosphorus uptake and improve plant resilience under stress conditions [23], and their effects are often more pronounced in biomass accumulation, root development, or yield [12]. In this research, AMF inoculation has been reported to enhance bulb weight without a marked impact on bulb number.

The trend observed in the present study, with slightly higher bulb numbers at the highest AMF dose, suggests a potential positive effect, though not statistically validated. This could be attributed to improved nutrient absorption and enhanced plant vigor facilitated by AMF. However, the lack of significant differences reinforces the idea that bulb number is a conservative trait, less responsive to external treatments compared to bulb weight or quality parameters.

3.4 Weight of Bulbs

The weight of bulbs is a direct indicator of yield and market value. Results from this experiment show clear differences among fertilizer treatments and AMF inoculation levels. Among fertilizers, NPK treatment achieved the highest bulb weight (29.26 g), followed closely by NK (28.28 g). The untreated control produced intermediate weights (23.56 g), while humic acid resulted in the lowest bulb weight (20.14 g). Statistical grouping placed NPK and NK together in the highest category, whereas humic acid was significantly inferior.

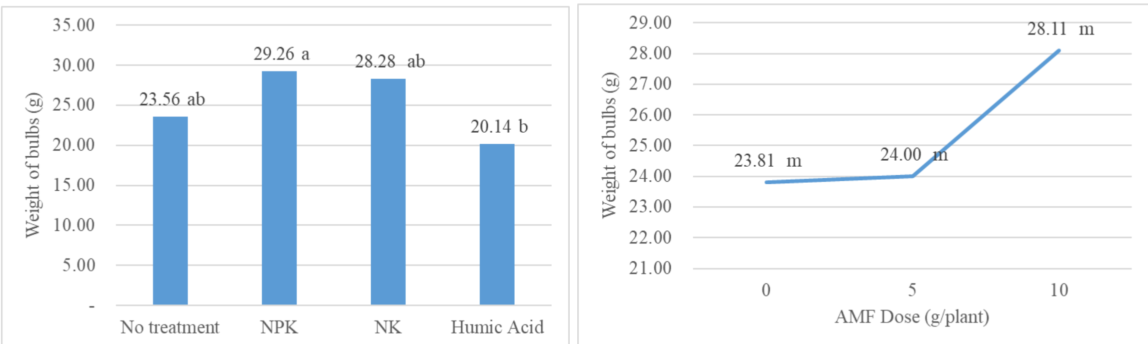

Figure 5
Effect of fertilizer types and arbuscular mycorrhizal fungi (AMF) doses on weight of bulbs of shallots under pot conditions. Different letters above the bars indicate significant differences according to Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$.

The advantage of NPK in increasing bulb weight is consistent with the role of phosphorus in energy metabolism and assimilate partitioning. While NK fertilizer supplied nitrogen and potassium, the lack of phosphorus likely limited the full expression of yield potential. Phosphorus deficiency restricts ATP production and reduces the efficiency of carbohydrate allocation into storage organs, leading to smaller bulbs. The slightly lower performance of NK compared with NPK in this study underscores the necessity of balanced macronutrient supply for maximizing bulb enlargement [24].

The low performance of humic acid alone confirms that while it enhances nutrient uptake efficiency and stimulates root activity, it cannot substitute for the essential macronutrients required for bulb filling. Previous studies have reported that humic substances increase crop performance primarily when combined with mineral nutrients [25]. The inferior bulb weight under humic acid treatment observed here supports this conclusion and indicates that its role is more supportive than primary in yield formation.

The effect of AMF inoculation on bulb weight followed a clear positive trend. Plants without inoculation yielded an average bulb weight of 23.81 g, while 5 g inoculation resulted in 24.00 g, and the highest dose (10 g) produced 28.11 g. Although the increase from 0 to 5 g was minimal, the improvement at 10 g was substantial, suggesting a threshold effect where higher inoculation densities provide sufficient fungal colonization to significantly enhance nutrient uptake. The observed increase of nearly 4.3 g between the uninoculated and 10 g treatments highlights the potential of AMF to improve sink strength and assimilate storage in shallots.

The mechanism underlying this improvement likely involves enhanced phosphorus and nitrogen uptake, as both are essential for bulb filling. AMF hyphae extend the root absorption zone, increasing access to immobile nutrients such as phosphorus [16]. Moreover, improved water relations under AMF colonization may sustain photosynthetic activity during bulb filling, resulting in greater carbohydrate translocation to storage organs [17]. Several studies have similarly reported significant yield gains under mycorrhizal inoculation, particularly when combined with balanced fertilization [11].

An important observation from these results is the complementary relationship between fertilizers and arbuscular mycorrhizal fungi (AMF). While mineral fertilizers, especially NPK, directly increase nutrient availability and drive yield formation, AMF enhance nutrient-use efficiency and provide resilience under less favorable conditions. The integration of these two strategies has the potential to reduce reliance on high fertilizer inputs while sustaining or even improving yields. This is particularly relevant for shallot production in regions where soil fertility is low and fertilizer costs are a constraint.

4. Conclusion

This study demonstrated that fertilization significantly influenced the growth and yield of shallots in pot experiments, whereas arbuscular mycorrhizal fungi (AMF) inoculation did not affect these parameters. NPK fertilizer consistently produced the greatest plant height and bulb weight, underscoring the importance of a balanced nutrient supply. Although AMF inoculation, particularly at 10 g per plant, did not increase bulb number or weight, it showed potential in enhancing nutrient uptake and assimilate allocation. Additionally, humic acid alone was less effective, but its potential as a complementary amendment remains evident. Integrating mineral fertilizers with AMF represents a promising strategy for improving shallot productivity and promoting soil sustainability..

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