JUATIKA
JURNAL AGRONOMI TANAMAN TROPIKA
VOL. 8 No. 2 May 2026

DOI :https://doi.org/10.36378/juatika.v8i2.5463
eissn 2656-1727
pissn 2684-785X
pages : 602 – 609

RESEARCH ARTICLE

Optimizing NPK Fertilization with Arbuscular Mycorrhizae Inoculation to Enhance Shallot (*Allium cepa L.*) Performance under Drought Stress

Nabil Hisyam[1], Saefurrohman[1,*], Yonny Koentjoro[1]

Abstract

Shallots are a high-value horticultural commodity in high demand due to their role in food security. While the demand for shallots increases significantly each year alongside population growth, it has not been matched by stable production increases due to cultivation constraints—one of which is unfavorable environmental factors such as drought. The low tolerance of the plants to water scarcity and their shallow root systems result in inhibited nutrient absorption and reduced yields. Therefore, efforts are needed to increase shallot production, such as through mycorrhizal inoculation and appropriate NPK fertilization. This study aims to determine the optimal combination of mycorrhizal inoculation dosage and NPK fertilizer dosage to influence the growth and yield of the 'Tajuk' shallot variety under drought stress conditions.This research was designed as a two-factor factorial experiment arranged in a Randomized Block Design (RBD). The first factor was the mycorrhiza dose, consisting of four treatment levels: 0 g/plant (Control), 5 g/plant, 15 g/plant, and 25 g/plant. The second factor was the NPK dose, consisting of three treatment levels: 300 kg/ha (Control), 270 kg/ha, and 240 kg/ha. The analysis results showed that the treatment with an NPK dose of 300 kg/ha and a mycorrhiza dose of 25 g/plant significantly increased plant height, root length, chlorophyll content, and dry weight.The prominent advantage of these findings lies in proving that mycorrhizal symbiosis acts as a powerful biological buffer, maximizing Nutrient Use Efficiency (NUE) and significantly enhancing the crop's physiological resilience against water deficit. Based on these results, it is highly recommended that farmers cultivating shallots in drylands or drought-prone areas integrate 25 g/plant of mycorrhizal inoculant with the standard 300 kg/ha NPK fertilization.

Keywords: Drought Stress, Mycorrhizae, NPK Fertilizer, Nutrient Use Efficiency, Shallot (*Allium cepa L.)*

1. Introduction

Shallot (*Allium cepa L.*) is an important vegetable crop from Alliaceae family known for producing cluster of small bulbs and is intensively used in Indonesian cuisine. Thedemand for shallot is relatively high. National shallot production was estimated to reach 2.09 million tons in 2024. However, in the first quarter of the year, production decreased by ~1.63 tons compared to the same period last year, which was 808.000 tons. Meanwhile, the average consumption of shallots is approximately 2.86 kg per capita per year and is expected to continue increasing in line with population growth (BPS, 2024).

A fundamental problem exacerbating this issue is the conventional reliance on high doses of synthetic fertilizers to compensate for poor growth. Under drought conditions, the lack of soil moisture severely restricts the mobility, solubility, and active uptake of these macronutrients. Consequently, applied fertilizers remain largely inaccessible to the roots, leading to critically low Nutrient Use Efficiency (NUE), economic losses for farmers, and an increased risk of soil degradation (Fanny et al., 2024). The reduction in soil water availability for plants leads to loss of cellular turgor pressure. This condition disrupts cellular activity, accelerates oxidative stress, reduces chlorophyll synthesis and photosynthesis functioning, as well as leads to premature leaf senescence and shoot death (Groszyk & Szechyńska-Hebda, 2025).

Drought stress also reduces the efficiency of nutrients

*Correspondence: saefurrohman.agro@upnjatim.ac.id
1) Universitas Pembangunan Nasional "Veteran" Jawa Timur - Jl. Rungkut Madya, Surabaya, Jawa Timur 60294, Indonesia

uptake due to impaired mass flow and diffusion of nutrient transport from the soil solution to the root surface (Seleiman et al., 2021). This physical constraints is further exacerbated by a decline in root activity due to the loss of cell turgor, thereby severely limiting the root's capacity to access and absorb nutrient ions —despite being abundantly available in the soil (Arifin et al., 2024). Within this condition, the effectivity of application of fertilizer, such as NPK, is reduced.

The use of mycorrhizae is among the appropriate strategy in alleviating drought stress and enhancing shallots growth and yields. Mycorrhizae, a mutualistic symbiotic fungi, colonize plant roots and form hyphae network extending into the soil that helps plants absorb water and nutrients normally unavailable to plant roots (Abdillah et al., 2022). In return, the plant supplies the fungi with carbon (e.g., sugar) from photosynthesis. Mychorrhizae also enhance nutrient absorption (e.g., N, P, K, Zn, Cu, etc.), synthesize osmoprotectants (proline, soluble sugar, etc.), improve antioxidant defense, and assist in plant hormonal regulation (Nawang Bulan et al., 2023). These mechanism collectively contribute to better plant tolerance, growth and yields under drought condition. Saputri and Lapanjang (2022) demonstrated that mycorrhizae innoculation in shallots results in higher plant height, more number of tillers, and higher biomass. Furthermore, earlier studies, such as Susanti et al. (2022), highlighted that Arbuscular Mycorrhizal Fungi (AMF) could act as biological buffers, potentially reducing the need for high chemical fertilizer inputs in *Allium* species under sub-optimal environments.

Despite these known benefits, previous studies have predominantly evaluated the effects of mycorrhizae and drought separately, or investigated them under fluctuating, naturally occurring field drought conditions without precisely regulating the stress level. Moreover, there is limited quantitative information regarding the synergistic interaction between varying mycorrhizal inoculum dosages and specifically reduced NPK fertilization rates.

Therefore, this research aimed to investigate the effects of mycorrhizal and NPK fertilizer application on the growth and yield of shallots under drought-stressed conditions. The shallots used were from Tajuk cultivar. Meanwhile, medium-level drought simulation was applied through the use of Polyethylene Glycol (PEG) 6000. The results of this research are expected to serve as a reference for developing more adaptive and efficient shallot cultivation technology to address environmental variability, thereby supporting production stability.

2. Material and Methods

2.1. Field Location and Experimental Design

A field experiment was conducted from September to November 2025 in Porong, Sidoarjo Regency, East Java Province (7° 32' 14.6148" S, 112° 41' 16.0296" E), at an elevation of approximately 4 meters above sea level (m a.s.l.). The field is located within a tropical savanna climate (Aw). The study commenced during the transition from the dry to the rainy season, with an average daily temperature ranging from 26°C to 34°C and a relative humidity of 65%–80%. The soil is predominantly alluvial with a clay loam texture, a pH of 6.0–7.0, and moderate organic matter content.

The experiment was designed as a two-factors factorial experiment arranged in a completely randomized block design (CRBD). The factors were mycorrhizal dosages (M): M0 = 0 g/plant (control), M1 = 5 g/plant, M2 = 15 g/plant, and M3 = 25 g/plant; and NPK dosages (P): P1 = NPK 300 kg/ha (control), P2 = NPK 270 kg/ha, and P3 = NPK 240 kg/ha. The factorial combination produced 12 combinations, each replicated 3 times, hence resulted in total 36 experimental units. Each units comprised 5 plant samples, hence resulted in total 720 plants population.

2.2. Materials, Preparation, and Plant Maintenance

The planting materials consisted of shallot sets of the Tajuk cultivar. The materials were obtained from local farmers in Nganjuk. The sets were selected based on specific criteria, including healthy and defect-free bulbs, a diameter of approximately ±3 cm, and an age of 90 days. Other materials used were manures, polyethylene glycol (PEG) 6000, NPK 161616 fertilizer, and chemicals, e.g., propineb, deltamethrin, for pest-disease control.

The experiment was commenced with land preparation, which included plowing, the formation of raised beds, and the application of manure (10 ton/ha). Subsequently, the shallot sets were planted in the soils with the apical portion oriented upward, while the basal portion was buried in the soil. Mycorrhizae (300 propagules/g) were applied three times at 0, 14, and 30 days after planting (DAP) according to the prescribed dosages.

Drought simulation was achieved by applying 10% (w/v) polyethylene glycol (PEG) 6000, which equaled to medium drought (-0.80-(-0.10) Mpa). Irrigation was applied twice weekly, alternating between water and 10% PEG until soil field capacity. NPK fertilizer was applied at 12, 25, and 40 DAP according to the prescribed dosages. Other maintenances included pest-disease control, weeding, etc. followed standard agronomical practices.

Harvesting was conducted at 60 days after planting (DAP) based on physiological maturity indicators, including wilted leaf bases, yellowing foliage, and purplish-red bulbs partially emerging above the soil surface. The plants were manually uprooted, after which five to ten shallot clusters were bundled together and immediately sun-dried for 3 days until the bulbs reached stable moisture content.

2.3. Data Observation and Analyses

Parameters observed included plant height (cm), number of leaves, root length (cm), plant dry weight (cm), and chlorophyll content. The data, excluding chlorophyll content, were tested for normality and homogeneity, then statistically analyzed using Analysis of Variance (ANOVA) based on a factorial Randomized Block Design (RBD). If the results showed a significant effect, they were further analyzed using Tukey's Honestly Significant Difference (HSD) test at the 5% significance level. All statistical analyses were performed using Microsoft Excel 2019 and Minitab version 20.4.

Plant length was observed every 7 days (from 14 to 42 Days After Planting/DAP) by measuring from the base to the longest tip of the plant using a ruler. Similarly, root length was measured from the base to the longest root tip using a ruler at harvest (60 DAP). For the dry weight parameter, measurements were taken precisely at harvest by weighing the dried plant biomass using an analytical balance. Meanwhile, the chlorophyll content was observed at 35 DAP using a representative sample. The chlorophyll analysis for this single-replication group followed the Harborne (1984) method.

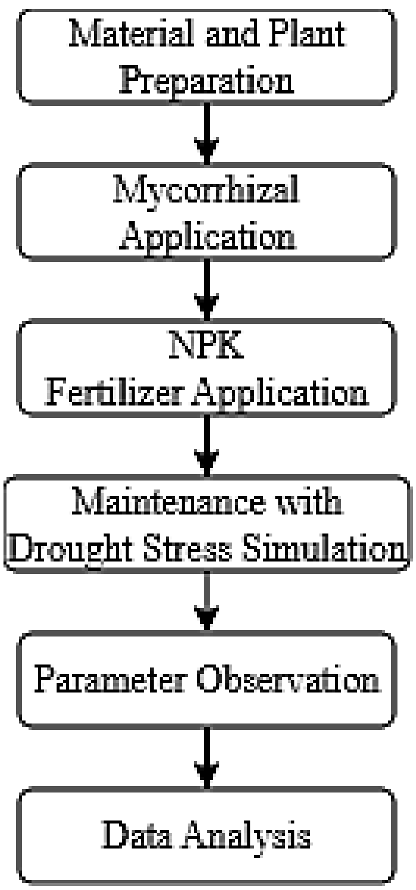

Figure 1. Research Flow Diagram.

3. Results and Discussion

3.1. Physical Properties of Soil

Soil physical property analysis was conducted to assess the effect of the intercropping system on changes in soil physical characteristics in oil palm land resulting from land conversion to rubber plantations. The results of this analysis are very important for assessing the physical quality of the soil and the effectiveness of nutrient absorption, root growth, and oil palm plant productivity in the intercropping system. To support this research, several physical characteristics of the soil were analyzed to identify changes that indicate an increase in the quality of oil palm soil in land conversion to rubber plantations based on corn and soybean *intercropping, namely*:

3.2. Plant Height

ANOVA showed no significant interaction between mycorrhizae and NPK dosages on plant height (Figure 2). Mycorrhizal inoculation significantly resulted in higher shallot plant height compared to the control. Mycorrhizal inoculation at 25 g/plant resulted in the highest plant height (23.93 cm at 35 DAP and 16.28 cm at 56 DAP). Similarly, NPK dosage significantly affected shallot plant height. The optimum dosage (300 kg/ha) resulted in the greatest plant height, while reduced dosages led to lower plant height at both 35 and 56 DAP.

Mycorrhizal inoculation, irrespective of NPK dosage, resulted in greater plant height compared to non-inoculated controls under drought stress. This is fundamentally driven by the extensive network of extraradical hyphae acting as a secondary root system. These hyphae penetrate soil micropores to scavenge residual moisture and immobile nutrients, particularly Phosphorus (Jabat et al., 2025). This enhanced water acquisition maintains the critical cell turgor pressure required for stem elongation and upregulates growth-promoting phytohormones to stimulate cell division (Liu et al., 2024). However, the baseline nutrient supply dictates the ultimate growth ceiling. While mycorrhizae ensure survival and prevent severe stunting at low NPK levels, optimal NPK doses are still strictly required to provide the structural (Nitrogen) and energetic (Phosphorus) building blocks necessary to maximize this vegetative growth potential.

Plant height increases linearly with optimal NPK doses because Nitrogen drives cell division and Phosphorus aids energy transfer (Fathi, 2022; Al Kahfy, 2025), while Potassium regulates cell turgor and stomatal opening under drought stress (Perelman et al., 2022). Conversely, reduced fertilizer doses severely hamper vegetative growth (Laksono, 2024). Acting additively, mycorrhizae mitigate drought by using external hyphae to absorb otherwise unreachable water and nutrients (Jabat et al., 2025), triggering growth-promoting hormonal changes (Liu et al., 2024) and functioning as biostimulants (Tang et al., 2022) without being inhibited by the highest NPK dosage (Nawang Bulan et al., 2023). However, observations indicated that plant height tended to decrease as the plants aged. This decline is attributed to the natural senescence phase of the plants, during which the tips of the shallot leaves begin to dry out and wither.

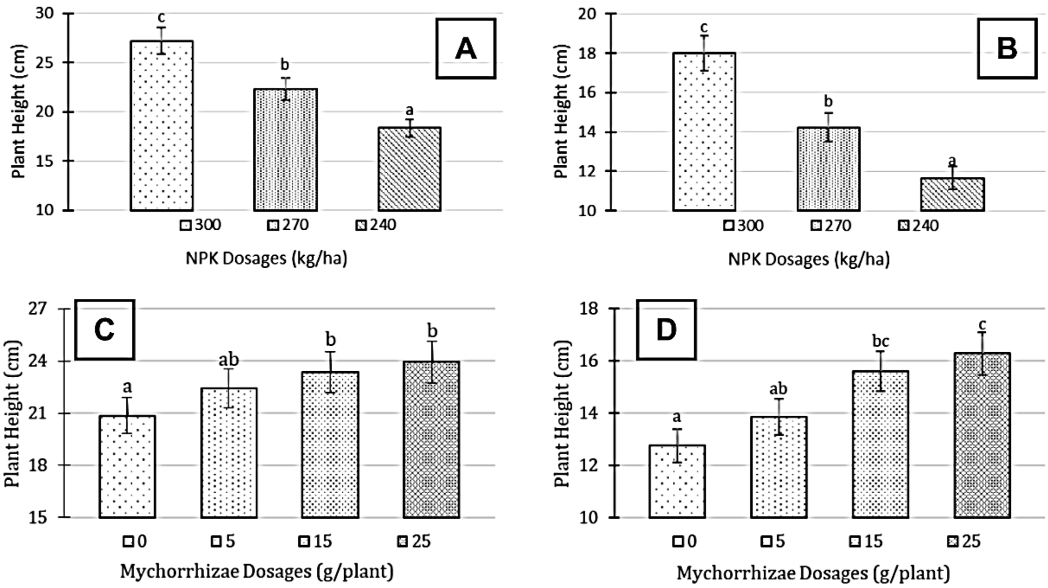

Figure 2. Shallot plant height under varying mycorrhizal dosages at 35 DAP (A) and 56 DAP (B), and under varying NPK dosages at 35 DAP (C) and 56 DAP (D). Letters above the bars indicate groupings based on Tukey's HSD test.

3.3. Shoot Dry Weight and Root Length

On the other hand, ANOVA showed a significant interaction between mycorrhizal inoculation and NPK dosages on root length and shoot dry weight (Figure 3). Similar trends were observed for both parameters, where mycorrhizal inoculation consistently resulted in greater root length and shoot dry weight compared to the non-inoculated control. Notably, mycorrhizal inoculation at all dosages (5, 10, and 15 g/plant) under reduced NPK levels (240 and 270 kg/ha) resulted in root length and shoot dry weight comparable to those obtained with the full NPK dosage (300 kg/ha) without mycorrhizal inoculation.

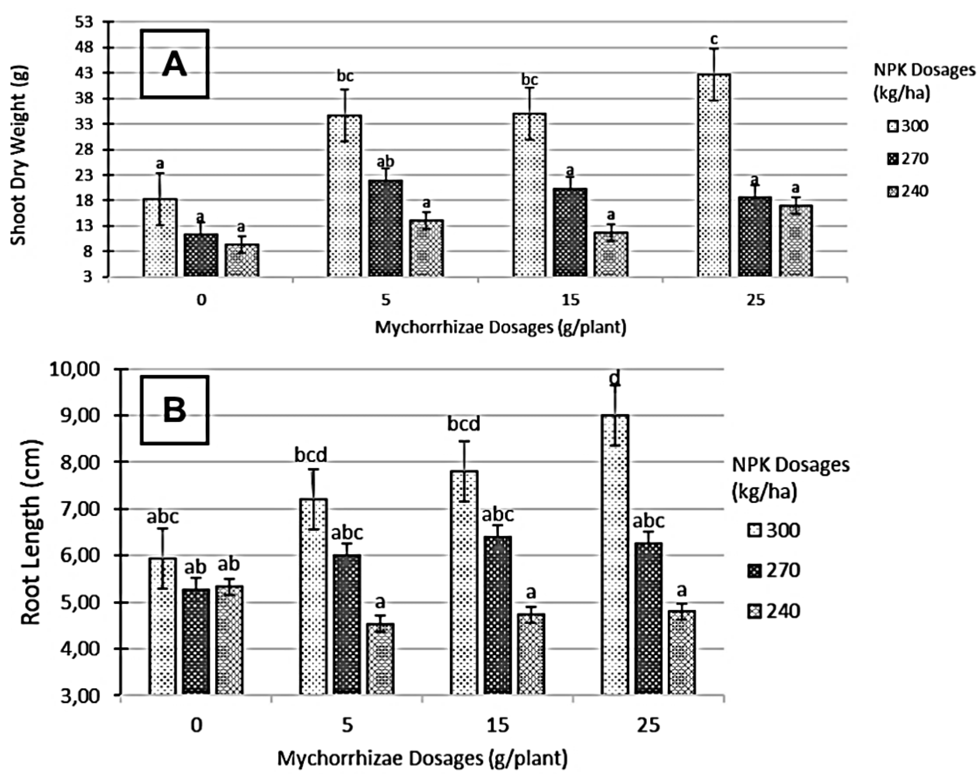

Figure 3. Shallot root length (A) and shoot dry weight (B) under varying mycorrhizal and NPK dosages. Letters above the bars indicate groupings based on Tukey's HSD test.

Quantitatively, this demonstrates that mycorrhizal application effectively offsets a 10% to 20% reduction in chemical fertilizer requirements without compromising plant biomass or root expansion. This finding aligns with the quantitative results of Tang et al. (2022), who reported that Arbuscular Mycorrhizal

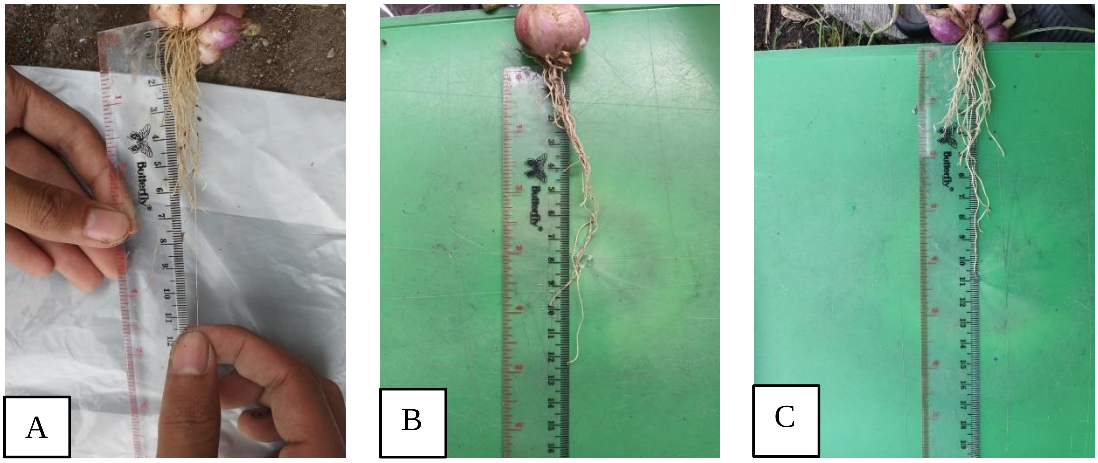

Figure 4. Root length comparison between treatment combinations,(A) 25 g/plant mycorrhizal and 300 kg/ha NPK ,(B) 10 g/plant mycorrhizal and 270 kg/ha NPK ,(C) 0 g/plant mycorrhizal and 240 kg/ha NPK.

Fungi (AMF) could reduce NPK fertilizer inputs by 15% to 25% in *Allium* species while maintaining optimal yields.

Furthermore, the ability of mycorrhizae to sustain biomass under a 20% fertilizer deficit corroborates the observations by Boutasknit et al. (2024), who documented a 20% to 30% increase in Nutrient Use Efficiency (NUE) when AMF was applied under water-limited conditions. Ultimately, these findings provide robust quantitative evidence that mycorrhizae act as a highly effective biological substitute, reducing agricultural reliance on synthetic fertilizers by up to one-fifth (20%) under drought stress.

Mycorrhizal inoculation enhanced root performance under drought stress, as reflected by increased root length. Roots are the primary organs affected under water-deficit conditions. As soil moisture drops, nutrient mobility severely decreases and soil mechanical resistance increases, restricting root elongation and impairing the uptake of water and essential dissolved nutrients. Mycorrhizae mitigate this physical limitation by developing an extensive network of extraradical hyphae that penetrate microscopic soil pores inaccessible to regular root hairs, effectively bypassing the root depletion zone (Boutasknit et al., 2024). This mechanism synergizes perfectly with NPK fertilizer application. Optimal NPK doses provide a crucial substrate of macronutrients in the soil—particularly Phosphorus for energy (ATP) and Nitrogen for cellular growth. The fungal hyphae efficiently scavenge these available NPK nutrients and translocate them to the host plant. In return, the well-nourished plant maintains a higher photosynthetic rate, providing abundant carbon exudates to fuel further hyphal expansion. This positive feedback loop ultimately maximizes root length and nutrient acquisition efficiency despite the drought (Maulana et al., 2025).

Recent studies further emphasize that Arbuscular Mycorrhizal Fungi (AMF) fundamentally alter root system architecture by enhancing fine root proliferation and spatial soil exploration, which is critical for maintaining water homeostasis under severe water [stress]. Similarly, the synergistic combination of 15g/plant mychorizae and 300kg/ha NPK produces the longest roots. This occurs because mycorrhizal hyphae enhance Phosphorus uptake (Muhammad et al., 2024), through a 'Functional Equilibrium' where sufficient NPK allows the plant to provide carbon exudates to support the fungi (Munene et al., 2025). However, at low NPK doses, this effectiveness drops because mycorrhizal benefits are highly dependent on basic soil nutrient status (Guo et al., 2024). Ultimately, these deep and extensive root systems are a vital morphological adaptation for surviving drought (Singh et al., 2022).

Mycorrhizal inoculation and NPK dosage also interacted to influence shallot biomass (shoot dry weight). Biomass reflects the cumulative outcome of plant physiological processes and their interaction with the growing environment. Drought conditions reduced biomass accumulation; however, the combined application of mycorrhizae and NPK enhanced shoot dry weight, indicating a positive interaction under water-limited conditions (Boutasknit et al., 2024). This synergism effectively minimizes the detrimental physiological effects of drought by maintaining cellular turgor and osmotic balance (Nawang Bulan et al., 2023). The extensive mycorrhizal hyphal network significantly increases the spatial availability and active uptake of essential nutrients, efficiently leveraging the Nitrogen and Phosphorus provided by the NPK substrate. This sustained hydration and enhanced nutritional status directly protect the photosynthetic apparatus from oxidative damage and maintain stomatal conductance, thereby increasing overall photosynthetic efficiency. The continuous carbon assimilation from this process is subsequently partitioned into structural biomass, driving the higher dry weight observed. Notably, a crucial finding of this study is that plants receiving a low NPK dosage combined with mycorrhizal inoculation achieved a shoot dry weight equivalent to those receiving the optimal NPK dosage without mycorrhizae. This demonstrates that mycorrhizae significantly enhance Nutrient Use Efficiency (NUE), acting as a powerful biological buffer that allows plants to maintain optimal biomass production under drought stress while potentially reducing the reliance on high chemical fertilizer inputs (Tang et al., 2022).

A significant interaction was observed in dry weight, with the 15g/plant mychorizae and 300kg/ha NPK combination yielding the highest biomass accumulation. Optimal AMF and NPK combinations maximize shoot and root dry matter by stimulating the accumulation of osmotic adjustment compounds (such as proline and soluble sugars) and reducing lipid peroxidation, thereby protecting cellular integrity from drought-induced damage. Mycorrhizae successfully maintain cell turgor and open stomata under drought (Nawang Bulan et al., 2023), allowing photosynthesis to remain optimal when supported by adequate NPK macronutrients.

Conversely, combining low fertilizer doses with mycorrhizae decreases dry weight due to the 'Carbon Cost' theory (Bisht et al., 2024). Under nutrient and water stress, plants must prioritize limited photosynthates for their own survival rather than feeding the fungi (Tang et al., 2022). This carbon limitation disrupts the delicate symbiotic economic balance, which can trigger 'growth depression' as the plant and fungi compete internally for scarce Nitrogen (Rui et al., 2022).

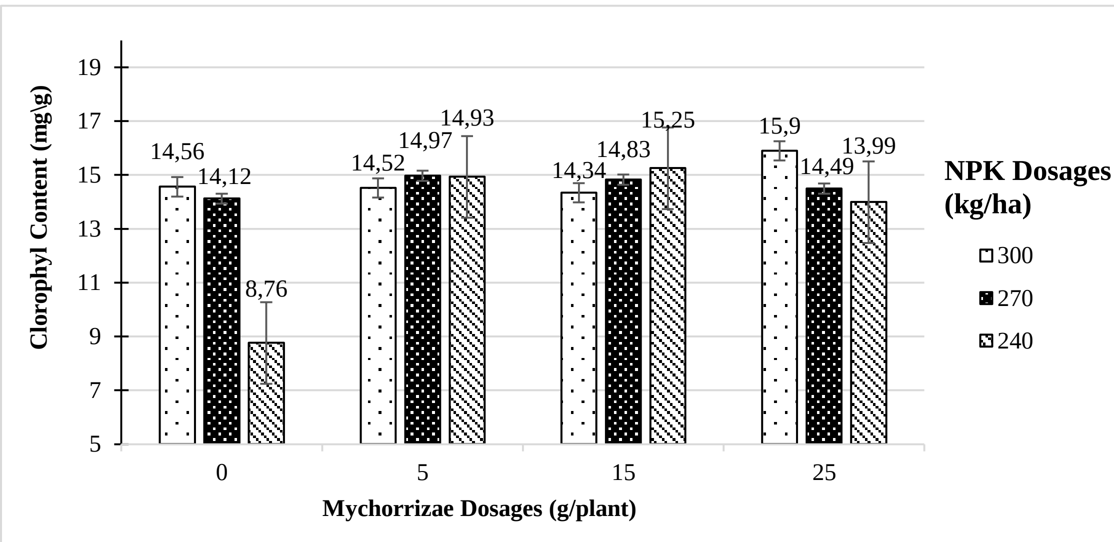

Figure 5. Chlorophyll content of shallot leaves under varying mycorrhizal and NPK dosages. Chlorophyll content was analyzed using the Harborne method without replication.

3.4. Chlorophyll Content

Furthermore, Figure 4 presents the chlorophyll content analyzed using the Harborne (1984) method. Statistical analysis was not performed, as the samples were processed without replication. The results showed that most samples tended to exhibit equal chlorophyll content. However, an exception was observed in the treatment without mycorrhizal inoculation and with 240 kg/ha NPK, which resulted in the lowest chlorophyll content (8.76 mg/g).

The combined application of mycorrhizae and NPK mitigated drought stress in shallot, as reflected in chlorophyll content. Chlorophyll levels were comparable across treatments, except in non-inoculated plants at the lowest NPK dosage, which showed reduced levels. This indicates that chlorophyll synthesis is constrained under nutrient deficiency, while mycorrhizal inoculation enhances chlorophyll formation even at low nutrient availability. As a key physiological indicator, chlorophyll content reflects plant responses to drought stress. Under water-deficit conditions, stomatal closure and the subsequent overproduction of Reactive Oxygen Species (ROS) typically accelerate the degradation of chloroplast membranes and photosynthetic pigments. However, optimal NPK fertilizer directly supplies essential Nitrogen—the core structural component of the chlorophyll porphyrin ring—and Phosphorus, which generates the ATP required for carbon assimilation (Fathi, 2022).

Concurrently, mycorrhizal inoculation acts as a vital physiological buffer. The extensive hyphal network enhances the sustained uptake of water and critical nutrients, including Magnesium, which serves as the central atom of the chlorophyll molecule. Furthermore, this symbiosis upregulates the host's antioxidant defense systems, effectively scavenging ROS and preventing drought-induced chlorophyll degradation (Liu et al., 2024). By preserving pigment stability and maintaining stomatal conductance through improved leaf turgor, this synergistic interaction ensures continuous CO2 assimilation, thereby maximizing overall photosynthetic efficiency. Chlorophyll levels were comparable across treatments, except in non-inoculated plants at the lowest NPK dosage, which showed reduced levels. This clearly indicates that chlorophyll synthesis is severely constrained under nutrient deficiency, while mycorrhizal inoculation successfully sustains chlorophyll formation and robust photosynthetic performance even at low nutrient availability.

The 15g/plant mychorizae and 300kg/ha NPK treatment yields the highest chlorophyll content due to optimal Nitrogen and Magnesium availability, as adequate Nitrogen is linearly correlated with chlorophyll synthesis (Fathi., 2022). Recent findings demonstrate that AMF inoculation not only preserves pigment concentration but also significantly enhances maximum photochemical efficiency (Fv/Fm) and optimizes the reactive oxygen species (ROS) scavenging system. Mycorrhizal colonization actively prevents chlorophyll degradation under stress by improving plant water status and antioxidant enzyme activity, which protects chloroplast membranes from oxidative damage (Liu et al., 2024). Additionally, mycorrhizae enhance Nitrogen Use Efficiency (NUE) (Tang et al., 2022), acting as a bio-protector that maintains high chlorophyll levels even at low fertilizer doses. Ultimately, this confirms that mycorrhizal effectiveness in drought mitigation heavily relies on providing sufficient basic NPK nutrients to support both the plant and the symbiont.

4. Conclusion

The synergistic application of mycorrhizae and NPK effectively alleviated PEG-induced drought stress in shallots, significantly enhancing overall plant height, root length, shoot dry weight, and chlorophyll content. Notably, the combination of 25 g/plant mycorrhizae and 300 kg/ha NPK emerged as the optimal strategy to maximize shallot growth and yield under water-deficit conditions.

References

Abdillah, L., Septian, M. H., & Sihite, M. (2022). Potensi pemanfaatan mikoriza arbuskula (AM) pada lahan hijauan pakan. *Journal of Livestock Science and Production, 5*(2), 362–370. https://doi.org/10.31002/jalspro.v5i2.5312

Abubakar, A. (2026). Respon pertumbuhan tanaman bawang merah (*Allium ascalonicum* L.) terhadap perlakuan pupuk kompos dan nitrogen. *Jurnal Pertanian Agros, 28*(1), 11–17.

Al Kahfy, M. R., & Nikmatullah, A. (2025). Pertumbuhan dan hasil tanaman bawang merah (*Allium ascalonicum* L.) varietas Tajuk pada perlakuan dosis pupuk NPK dan konsentrasi pupuk organik cair Hens. *Jurnal Ilmiah Mahasiswa Agrokomplek, 4*(2), 370–377. https://doi.org/10.29303/jima.v4i2.7151

Arifin, M., Nurhayati, N., & Kurniawan, T. (2024). Pengaruh dosis pupuk NPK dan kompos terhadap pertumbuhan dan hasil tanaman bawang merah (*Allium ascalonicum* L.). *Jurnal Floratek, 19*(1), 1–13. https://doi.org/10.17969/floratek.v19i1.36261

Bisht, A., Lather, S., Goyal, P., & Garg, N. (2024). Molecular determinants and regulatory mechanisms of nutrient exchange between plant and AMF. In *Arbuscular mycorrhizal fungi in sustainable agriculture: Nutrient and crop management* (pp. 77–97). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-0300-5_3

Badan Pusat Statistik. (2024). *Produksi tanaman sayuran dan buah-buahan semusim menurut provinsi dan jenis tanaman 2022*. https://www.bps.go.id/id/statistics-table/3/ZUhFd1JtZzJWVVpqWTJsV05XTllhVmhRSzFoNFFUMDkjMw==/produksi-tanaman-sayuran-dan-buah-buahan-semusim-menurut-provinsi-dan-jenis-tanaman----2022.html?year=2024

Boutasknit, A., Baslam, M., Ait-El-Mokhtar, M., Anli, M., Ben-Laouane, R., Douira, A., El Modafar, C., Mitsui, T., Wahbi, S., & Meddich, A. (2024). Arbuscular mycorrhizal fungi mediate drought tolerance and recovery in two contrasting carob (*Ceratonia siliqua* L.) ecotypes by regulating stomatal, water relations, and (in)organic adjustments. *Plants, 9*(1), 80. https://doi.org/10.3390/plants9010080

Dietz, K.-J., Zörb, C., & Geilfus, C.-M. (2021). Drought and crop yield. *Plant Biology, 23*(6), 881–893. https://doi.org/10.1111/plb.13304

Fanny, T., Eliyani, E., & Kurniadinata, O. F. (2020). Can we grow shallot (*Allium ascalonicum* L.) root in hydroponic system with simple growing media? *Journal of Tropical Horticulture, 3*(2), 54–59. https://doi.org/10.33089/jthort.v3i2.50

Fathi, A. (2022). Role of nitrogen (N) in plant growth, photosynthesis pigments, and N use efficiency: A review. *Agrisost, 28*, 1–8. https://doi.org/10.5281/zenodo.7438164

Groszyk, J., & Szechyńska-Hebda, M. (2021). Effects of 24-epibrassinolide, bikinin, and brassinazole on barley growth under salinity stress are genotype- and dose-dependent. *Agronomy, 11*(2), 259. https://doi.org/10.3390/agronomy11020259

Guo, S., Xia, L., Xia, D., Li, M., Xu, W., & Liu, L. (2024). Enhancing plant resilience: Arbuscular mycorrhizal fungi's role in alleviating drought stress in vegetation concrete. *Frontiers in Plant Science, 15*, Article 1401050. https://doi.org/10.3389/fpls.2024.1401050

Jabat, Y. Y. L. B., Napitupulu, B. S., & Gulo, G. K. (2025). Respon pertumbuhan dan produksi bawang merah (*Allium ascalonicum* L.) terhadap pemberian cendawan mikoriza arbuskula dan pupuk NPK. *Jurnal Agro Estate, 9*(2), 55–62. https://doi.org/10.47199/jae.v9i2.357

Laksono, M. C. D. (2024). Pengaruh pemberian pupuk organik Eco Farming dan pupuk NPK terhadap pertumbuhan dan hasil tanaman bawang merah (*Allium ascalonicum* L.). *Proceedings Series on Physical & Formal Sciences, 7*, 81–89. https://doi.org/10.30595/pspfs.v7i.1205

Liu, C.-Y., Hao, Y., Wu, X.-L., Dai, F.-J., Abd-Allah, E. F., Wu, Q.-S., & Liu, S.-R. (2024). Arbuscular mycorrhizal fungi improve drought tolerance of tea plants via modulating root architecture and hormones. *Plant Growth Regulation, 102*(1), 13–22. https://doi.org/10.1007/s10725-023-00972-8

Maulana, M., Suswati, Noer, Z., & Syafruddin. (2025). Mycorrhizal application and dosage material organic towards increasing chili pepper production (*Capsicum frutescens*) on goal plant cocoa. *Jurnal Agronomi Tanaman Tropika (Juatika), 7*(3), 967–976. https://doi.org/10.36378/juatika.v7i3.4967

Muhammad, M., Fajri, A. D., Parwi, P., Parwito, P., & Susilo, E. (2024). Response of growth and production of shallot to the genus of mycorrhiza and NPK fertilizer. *SINTA Journal (Science, Technology, and Agricultural), 4*(2), 139–150. https://doi.org/10.37638/sinta.4.2.139-150

Munene, R., Mustafa, O., Loftus, S., Banfield, C. C., Rötter, R. P., Bore, E. K., Mweu, B., Mganga, K. Z., Otieno, D. O., Ahmed, M. A., & Dippold, M. A. (2025). Contribution of arbuscular mycorrhiza and exoenzymes to nitrogen acquisition of sorghum under drought. *Frontiers in Plant Science, 16*, Article 1514416. https://doi.org/10.3389/fpls.2025.1514416

Nawang Bulan, P. A., Ariyanti, N. A., Aloysius, S., & Sugiyarto, L. (2023). Pengaruh pemberian mikoriza, *Trichoderma* sp., terhadap pertumbuhan bawang merah (Crok Kuning) pada cekaman kekeringan. *Jurnal Penelitian Saintek, 1*(1). https://doi.org/10.21831/jps.v1i1.56022

Perelman, A., Imas, P., & Bansal, S. K. (2022). Potassium role in plants' response to abiotic stresses. In *Role of potassium in abiotic stress* (pp. 15–39). Springer Nature Singapore. https://doi.org/10.1007/978-981-16-4461-0_2

Rui, W., Mao, Z., & Li, Z. (2022). The roles of phosphorus and nitrogen nutrient transporters in the arbuscular mycorrhizal symbiosis. *International Journal of Molecular Sciences, 23*(19), 11027. https://doi.org/10.3390/ijms231911027

Saputri, H. A., & Lapanjang, I. (2022). Pengaruh pemberian mikoriza terhadap pertumbuhan dan hasil tanaman bawang merah varietas Lembah Palu. *Agrotekbis: Jurnal Ilmu Pertanian, 10*(1), 64–72.

Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., Dindaroglu, T., Abdul-Wajid, H. H., & Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants, 10*(2), 259. https://doi.org/10.3390/plants10020259

Singh, M., Bisht, S., Singh, S., & Sharma, J. G. (2022). Implications of abiotic stress tolerance in arbuscular mycorrhiza-colonized plants: Importance in plant growth and regulation. *Journal of Applied Biology & Biotechnology*. https://doi.org/10.7324/JABB.2022.100601

Susanti, Ambar, Abdul Aziz, A., & Muhibuddin, A. (2021). The effectiveness of addition mycorrhizae and fertilizer composition on the spinach's growth (*Amaranthus* sp.). *Jurnal Agronomi Tanaman Tropika (Juatika), 3*(2), 135–147. https://doi.org/10.36378/juatika.v3i2.1396

Sutardi, Kristamtini, Purwaningsih, H., Widyayanti, S., Arianti, F. D., Pertiwi, M. D., Triastono, J., Praptana, R. H., Malik, A., Cempaka, I. G., Yusuf, M. P., Anda, M., & Wihardjaka, A. (2022). Nutrient management of shallot farming in sandy loam soil in Tegalrejo, Gunungkidul, Indonesia. *Sustainability, 14*(19), 11862. https://doi.org/10.3390/su141911862

Tang, H., Hassan, M. U., Feng, L., Nawaz, M., Shah, A. N., Qari, S. H., Liu, Y., & Miao, J. (2022). The critical role of arbuscular mycorrhizal fungi to improve drought tolerance and nitrogen use efficiency in crops. *Frontiers in Plant Science, 13*, Article 919166. https://doi.org/10.3389/fpls.2022.919166

Yin, Z., He, Y., Zhang, Y., Guo, W., Xie, X., & Yin, F. (2024). Nitrogen, phosphorus, and potassium interactive effects for improving drought resistance on mung bean varieties. *American Journal of Plant Sciences, 15*(9), 777–795. https://doi.org/10.4236/ajps.2024.159050