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Manure as a soil amendment: alleviating water deficit impact on shallot (*Allium ascalonicum* L.) growth and development

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ABSTRACT

This study evaluated the role of manure in mitigating drought stress and enhancing shallot (*Allium ascalonicum* L.) performance. A factorial randomized block design was implemented with three drought timings (early growth, vegetative, and bulb formation) and three manure doses (0, 10, and 20 t ha^{-1}). Results showed that the vegetative phase was the most drought-sensitive, with reductions of 55% in fresh biomass and 40% in dry biomass relative to the control. Leaf area declined by 49.2%, while plant length and leaf number decreased by 22–25%. Application of 20 t ha^{-1} manure consistently alleviated drought effects across all stages, increasing biomass by 20–30% and bulb weight by up to 30.4% compared with unfertilized plants. Drought reduced bulb diameter by 14.5% during the vegetative phase, but this decline was mitigated to 10.5% with manure addition. These findings demonstrate that 20 t ha^{-1} goat manure is an effective dose for improving shallot growth and yield under water deficit, providing a practical strategy to sustain production in drought-prone regions.

Keywords: water deficit, drought timing, goat manure, shallot.

INTRODUCTION

Shallots (*Allium ascalonicum* L.) are a type of onion belonging to the Allium genus, specifically classified under the Aggregatum group, which includes onions with smaller, clustered bulbs distinct from the common onion (*Allium cepa* L.). Shallots are a key vegetable crop in Southeast Asia, valued for their distinctive flavor and health-promoting compounds such as quercetin and kaempferol, which provide antioxidant and antimicrobial properties (Moldovan et al., 2022). Indonesia is the largest regional producer, contributing over 80% of total production Asia (Calica and Dulay, 2018). Despite this dominance, yield stability remains a persistent challenge due to environmental stressors, particularly drought. Shallot cultivation is concentrated in the dry season to avoid disease pressure during the rains, but low rainfall and shallow root systems increase vulnerability to water deficits (Hadiawati et al., 2023). Climate change has exacerbated this problem by shifting rainfall patterns and intensifying drought episode.

Plant growth and development are significantly affected by drought stress due to the inhibition of enzymatic activity, reduced cell size, impaired cell division, and decreased turgor pressure, all of which ultimately lead to a decline in photosynthetic activity (Ishaku et al., 2020). The extent of this impact varies across different growth stages, as each phase has specific water requirements and physiological processes that influence the plant's ability to withstand drought. Drought stress during critical growth phases disrupts essential metabolic functions, leading to reduced nutrient uptake, limited carbohydrate synthesis, and impaired energy metabolism (Pratiwi et al., 2024b). In shallots, water deficit can reduce dry bulb weight by 49–69% depending on the growth phase, with the vegetative and bulb initiation stages being especially sensitive (Pratiwi et al., 2024a). These findings highlight the importance of sufficient water availability at critical growth stages to minimize yield losses and maintain optimal shallot production under drought conditions.

The application of organic fertilizers has been widely recognized as an effective strategy to enhance soil quality and improve plant resilience under drought conditions. Organic amendments, such as manure, compost, biochar, and vermicompost, contribute to soil health by increasing soil organic matter content, enhancing mineral nutrient availability, and improving soil structure, which collectively enhance water-holding capacity and reduce moisture loss through evaporation (Boutasknit et al., 2020; Liu et al., 2024). Additionally, organic matter application has been shown to induce drought tolerance by stimulating microbial activity and promoting a higher fungal-to-bacterial ratio in the soil, which enhances nutrient cycling and root development, allowing plants to access water more efficiently (Fallah et al., 2021). Several studies have shown the effectiveness of manure in mitigating drought stress in crops: goat manure improved garlic growth under 50% water deficit (Turfan, 2021) while cow manure increased wheat yield by up to 130% under drought (Dimkpa et al., 2020). Vermicompost also enhanced physiological responses in lettuce, leading to improved growth and water-use efficiency (Kiran, 2019).

Despite the well-documented benefits of manure in improving soil fertility and plant growth, its role in mitigating drought stress in shallots remains unclear. Limited research has explored how manure application influences shallot growth and yield under water-limited conditions, highlighting the need for further investigation. Determining the appropriate manure dosage is essential to maximizing its benefits. Therefore, this study aimed to evaluate the effectiveness of goat manure in alleviating drought stress during different growth phases of shallots. Specifically, we tested whether manure application could mitigate the negative effects of water deficit on growth, biomass accumulation, and yield components, and we identified the dosage that provides the greatest benefit. The findings are expected to contribute to improved manure management strategies for shallot cultivation in drought-prone areas.

MATERIALS AND METHODS

The experiment was conducted in Malang Regency, East Java, Indonesia (500–600 m a.s.l.) in 2024. Average daily temperature during the trial was 20–22 °C. Shallot plants were grown in planting boxes measuring 80 × 80 × 30 cm, covered with plastic shelters to prevent rainwater intrusion throughout the experimental period. The growing medium was a mixture of topsoil (0–30 cm) and goat manure applied according to the respective treatments. The soil was classified as clay loam (46% sand, 38% silt, 16% clay) with pH 6.4, low organic C (0.62%), low total N (0.17%), high available P (157 ppm), and very high exchangeable K (110 mg 100 g^{-1}). The goat manure used contained 37.35% organic C, 2.51% N, 0.38% P_2O_5, 2.36% K_2O, pH 7.2, and 10.61% moisture.

Uniform bulbs of the Batu Ijo variety were planted in boxes (80 × 80 × 30 cm) covered with plastic shelters. Each bulb was cut at one-quarter of its top portion before planting at 20 × 20 cm spacing. Basal fertilization followed recommended doses of 200 kg ha^{-1} N, 120 kg ha^{-1} P_2O_5, and 120 kg ha^{-1} K_2O, split into three applications at 7, 21, and 35 days after planting (DAP). Standard cultural practices, including weeding and pest control, were performed as required.

A factorial randomized block design (RBD) was applied, consisting of four drought treatments [C0 = well-watered control, C1 = stress during early growth (1–15 DAP), C2 = stress during vegetative phase (16–30 DAP), C3 = stress during bulb formation (31–45 DAP)] and three manure doses (0, 10, and 20 t ha^{-1}). This resulted in 12 treatment combinations with three replications (36 experimental units). Drought stress was induced by withholding irrigation during the specified growth phases. In control plots, irrigation was applied every four days to maintain field capacity.

Growth parameters observed included plant height, number of leaves, leaf area, total fresh weight, total dry weight. For plant dry weight measurement, the entire plant, including roots, stems, leaves, and bulbs, was used. The samples were then oven-dried at a constant temperature of 80 °C for 48 hours (2 × 24 hours). Harvesting was performed when the leaves began to yellow and fall over. Yield components (bulb number, diameter, and fresh weight) were determined at harvest after 14 days of curing under shade. The net assimilation rate (NAR) and relative growth rate (RGR) were calculated following Setyowati et al. (2014), using leaf area and dry biomass values.

$$\text{NAR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\ln A_2 - \ln A_1}{A_2 - A_1} \quad (1)$$

$$\text{RGR} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1} \quad (2)$$

where: W_1 and W_2 – plant dry weight at time t_1 and t_2 (g), A_1 and A_2 – leaf area at time t_1 and t_2 (cm^2), t_1 and t_2 – time of measurement (days).

Proline content was quantified following the colorimetric method of Bates, with slight modifications as described by Sudhakar et al. (2016). Fresh leaf tissue (0.5 g) was homogenized in 10 mL of 3% (w/v) sulfosalicylic acid and centrifuged at 10.000 × g for 10 min. Two milliliters of the clear supernatant were reacted with 2 mL of acid ninhydrin reagent (1.25 g ninhydrin in 30 mL glacial acetic acid and 20 mL 6 M phosphoric acid) and 2 mL of glacial acetic acid in a test tube. The mixture was incubated in a water bath at 100 °C for 1 h and then cooled on ice. The chromophore was extracted with 4 mL toluene by vigorous mixing for 30 s, and the absorbance of the toluene phase was measured at 520 nm using a UV–Vis spectrophotometer. A standard curve was constructed using L-proline, and proline content was expressed as μmol g^{-1} fresh weight (FW).

The collected data were analyzed using the analysis of variance (ANOVA) function using DSAASTAAT. Multiple comparisons of means were checked at $P \leq 0.05$ using the honestly significant difference (HSD) test. In addition, all diagrams were created using OriginPro 2025.

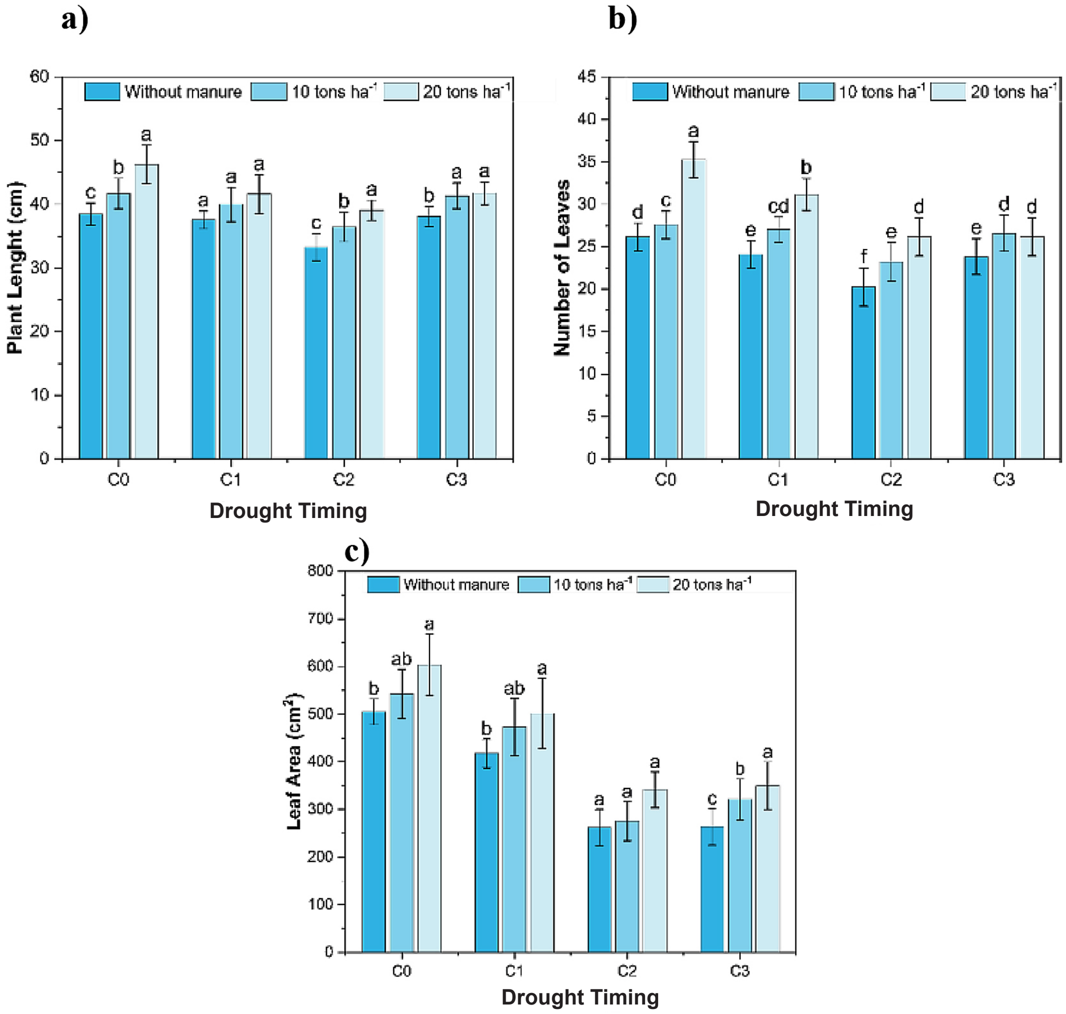

Figure 1. Effects of drought timing (C0 = control; C1 = 1–15 DAP; C2 = 16–30 DAP; C3 = 31–45 DAP) and manure dose (0, 10, 20 t ha^{-1}) on (a) plant height, (b) leaf number, and (c) leaf area of shallot. Bars represent mean ± SD (n = 3). Different letters indicate significant differences (HSD, $p \leq 0.05$)

RESULTS AND DISCUSSION

Across measurement dates, drought timing significantly affected plant height, leaf number, and leaf area, with the vegetative phase (C2, 16–30 DAP) consistently presenting the largest reductions relative to the well-watered control (C0). Height and leaf number declined by 22–25%, whereas leaf area declined by 43–49%. Application of 20 t ha^{-1} goat manure counteracted these losses, increasing leaf number by about 29% under vegetative-phase stress and sustaining leaf expansion compared with unfertilized plants (Figure 1).

From a mechanistic standpoint, leaf area reduction is one of the earliest and most sensitive indicators of water limitation. Shallots, with their inherently shallow root system, are unable to exploit deeper soil water reserves; thus, even short interruptions in irrigation directly reduce turgor pressure in expanding leaves. Turgor loss limits epidermal cell expansion and cell wall loosening, leading to smaller lamina. This explains why the reduction in leaf area (49%) was more severe than the reduction in plant height or leaf number (22–25%). In addition, drought triggers stomatal closure to minimize transpiration, which reduces CO_2 influx and lowers photosynthetic rate, compounding the growth restriction. The reduced leaf area is also a consequence of lost turgor pressure caused by stomatal closure, chloroplast fragmentation, and decreased water and chlorophyll content, which directly affect photosynthetic activity and leaf cell expansion (Fahad et al., 2017; Potopová et al., 2016).

Comparing the timing of stress, the data reinforce that the vegetative phase is the critical window for shallot production. Stress during this phase caused decreases in plant length, leaf number, and leaf area by 22–25%, 22–25%, and 43–49%, respectively, compared to unstressed conditions. This stage coincides with rapid canopy expansion and sink establishment, so limitations in water and nutrient uptake during this period have cascading effects on later biomass accumulation and yield formation. This finding agrees with results in cereals where vegetative-stage drought has long-lasting consequences for tiller development and leaf area index (Abid et al., 2016; Z. Xu et al., 2010). For shallots, which rely on cumulative photosynthate from an adequate canopy to support bulb initiation, loss of leaf area during C2 directly constrains future sink size.

An important nuance is the partial resilience observed under early drought (C1). Although plants experienced water limitation during the first 15 days, their relatively small canopy and low transpiration demand at this stage meant stress was less damaging. Once irrigation was resumed, plants compensated with increased growth rates, a phenomenon known as compensatory growth. Early-stage plants also exhibit enhanced physiological flexibility, enabling them to rapidly adjust their water use efficiency and metabolic processes in response to stress conditions. These traits contribute to a greater capacity for recovery, especially when water availability is restored before critical developmental stages such as bulb initiation and enlargement (Z. Xu et al., 2010). This recovery pattern is consistent with Cui et al. (2021), who demonstrated that drought timing determines biomass accumulation outcomes in soybeans, with early-stage stress allowing complete recovery while reproductive-stage drought results in irreversible biomass decline. This explains why the final height and leaf area of C1 plants were closer to control values compared with C2. Such recovery capacity, however, diminishes as plants age and sink demand rises.

The beneficial role of manure can be attributed to multiple, overlapping processes. Organic matter improves soil water retention capacity by increasing porosity and the fraction of water held at plant-available tensions. Studies on onion and garlic similarly reported that organic amendments reduced water stress by enhancing the soil sponge effect and maintaining higher relative water content in leaves (Boutasknit et al., 2020; Turfan, 2021). Manure provides a slow-release source of N, P, and K. Sufficient nutrient availability, especially nitrogen, phosphorus, and potassium, is crucial for maintaining plant metabolic activity and physiological processes under stress conditions (Yousefvand et al., 2024). Adequate N supports chlorophyll synthesis and Rubisco activity, thereby sustaining photosynthesis under moderate stress. P improves root growth and energy transfer, while K regulates osmotic balance and stomatal movement, both critical under drought. Manure stimulates microbial activity in the rhizosphere, leading to greater mineralization of nutrients and possible production of plant growth regulators such as auxins and cytokinins that promote leaf initiation and expansion. These microorganisms can help plants access water and nutrients under stress conditions and produce bioactive compounds such as growth hormones and osmolytes that increase plant drought tolerance (Candra et al., 2023). Such microbial activity has been shown to trigger the formation of growth regulators like auxins and cytokinins, which play important roles in lateral root development and cell elongation under water deficit conditions (Dubey et al., 2021; L. Xu et al., 2015).

Manure fertilizer application at 20 t ha^{-1} consistently provided protective effects against drought stress negative impacts on all growth parameters, although with varying effectiveness depending on the plant growth phase during stress. Under optimal conditions without stress (C0), 20 t ha^{-1} manure application produced significant improvements in all growth parameters, with up to a 34.71% increase in leaf number compared to no manure treatment. This demonstrates the important role of organic fertilizers in enhancing plant growth even under non-stress conditions by providing balanced nutrition and improving soil structure (Hartatik et al., 2015).

Fresh and dry biomass mirrored morphological responses. Vegetative-phase drought caused the largest losses (−55% fresh, −40% dry relative to C0), whereas early-phase drought (C1, 1–15 DAP) showed partial recoverability once watering resumed; bulb-formation stress (C3, 31–45 DAP) produced intermediate losses (Figure 2). Manure at 20 t ha^{-1} consistently lifted fresh and dry biomass by 20–30% across phases, highlighting its broad mitigating effect.

Physiologically, the vegetative window is a high-demand period when leaf area index, root proliferation, and sink establishment co-occur. Water deficit here depresses net C gain through combined stomatal and non-stomatal limitations, curtails phloem loading, and reallocates assimilates from growth to maintenance and defense. Even shortfalls in this window propagate forward via reduced source strength and smaller meristematic sinks, explaining the disproportionate biomass penalty relative to other phases (Kim et al., 2013; Nonami, 1998). In contrast, early-phase stress coincides with lower canopy demand, greater plasticity, and higher potential for compensatory growth following rehydration, as documented in cereals and legumes where post-stress WUE improves and growth rebounds once hydraulic status is restored (Abid et al., 2016, 2018; Z. Xu et al., 2010).

Drought stress significantly restricts biomass accumulation through multiple physiological mechanisms affecting plant growth and development. The reduction in soil water content during drought conditions directly impairs mineral and nutrient uptake from soil systems, as decreased cellular and tissue water content limits the plant's capacity for metabolic processes essential for biomass formation (Rekaby et al., 2019). Water serves as the primary medium for nutrient dissolution and transport within plant tissues, and reduced soil moisture substantially diminishes root assimilation capacity, consequently limiting the availability of essential elements required for biomass synthesis (Oguz et al., 2022). These nutrient and water limitations manifest as reduced fresh and dry biomass production during vegetative

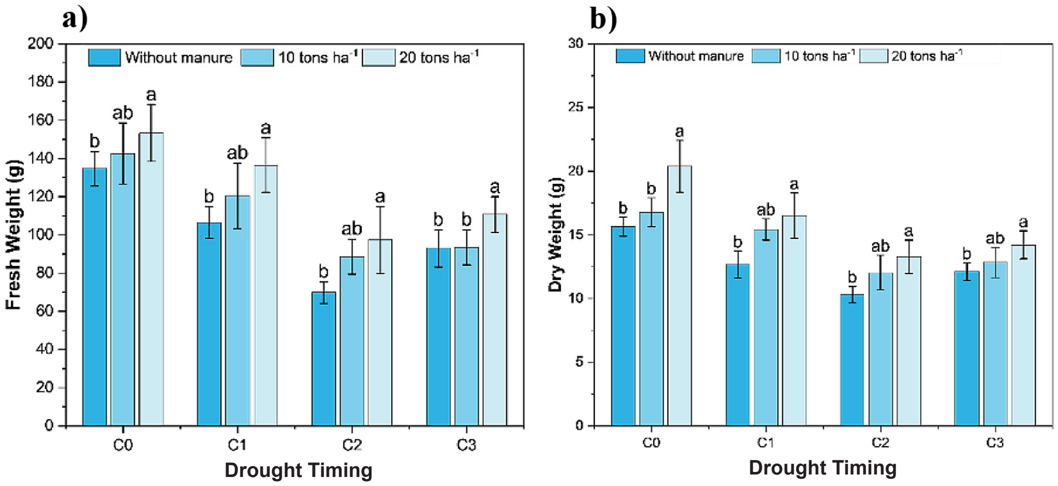

Figure 2. Effects of drought timing (C0 = control; C1 = 1–15 DAP; C2 = 16–30 DAP; C3 = 31–45 DAP) and manure dose (0, 10, 20 t ha^{-1}) on (a) fresh weight and (b) dry weight of shallot. Bars represent mean ± SD (n = 3). Different letters indicate significant differences (HSD, $p \leq 0.05$)

growth stages, accompanied by delayed tillering responses, accelerated maturity, and increased plant mortality rates (Lidon, 2012). The cumulative effect of these physiological constraints results in significant reductions in total biomass accumulation, demonstrating the critical impact of drought stress on plant productivity.

The application of organic amendments, particularly manure incorporation, demonstrates substantial effectiveness in restoring biomass accumulation capacity under drought-stress conditions. The 20–30% biomass increase observed in plants receiving 20 t ha^{-1} manure application compared to unfertilized controls indicates a significant enhancement of biomass production despite water limitations. This biomass improvement directly correlates with enhanced root system development, as Abdelrasheed et al. (2021) documented substantial increases in root length, biomass, and hair density in biochar-amended soils, facilitating improved resource acquisition for biomass synthesis during drought periods. Stimulation of rhizosphere microbes, including PGPR and mycorrhizae, that enhance nutrient solubilization and produce phytohormones promoting root growth and lateral branching (Zhou et al., 2018). By deepening and densifying the root system and extending hydraulic access, manure helps convert episodic water supply into more stable plant-available moisture, translating into steadier biomass accrual.

Our results revealed the influence of manure fertilizer application in mitigating drought stress impacts on shallot productivity. We found that drought stress significantly reduced bulb diameter, especially during the vegetative phase (C2) with reduction reaching 14.5% compared to control (Figure 3a). However, 20 t ha^{-1} manure application was able to suppress this reduction to 10.5%. Bulb number (Figure 3b) indicated that

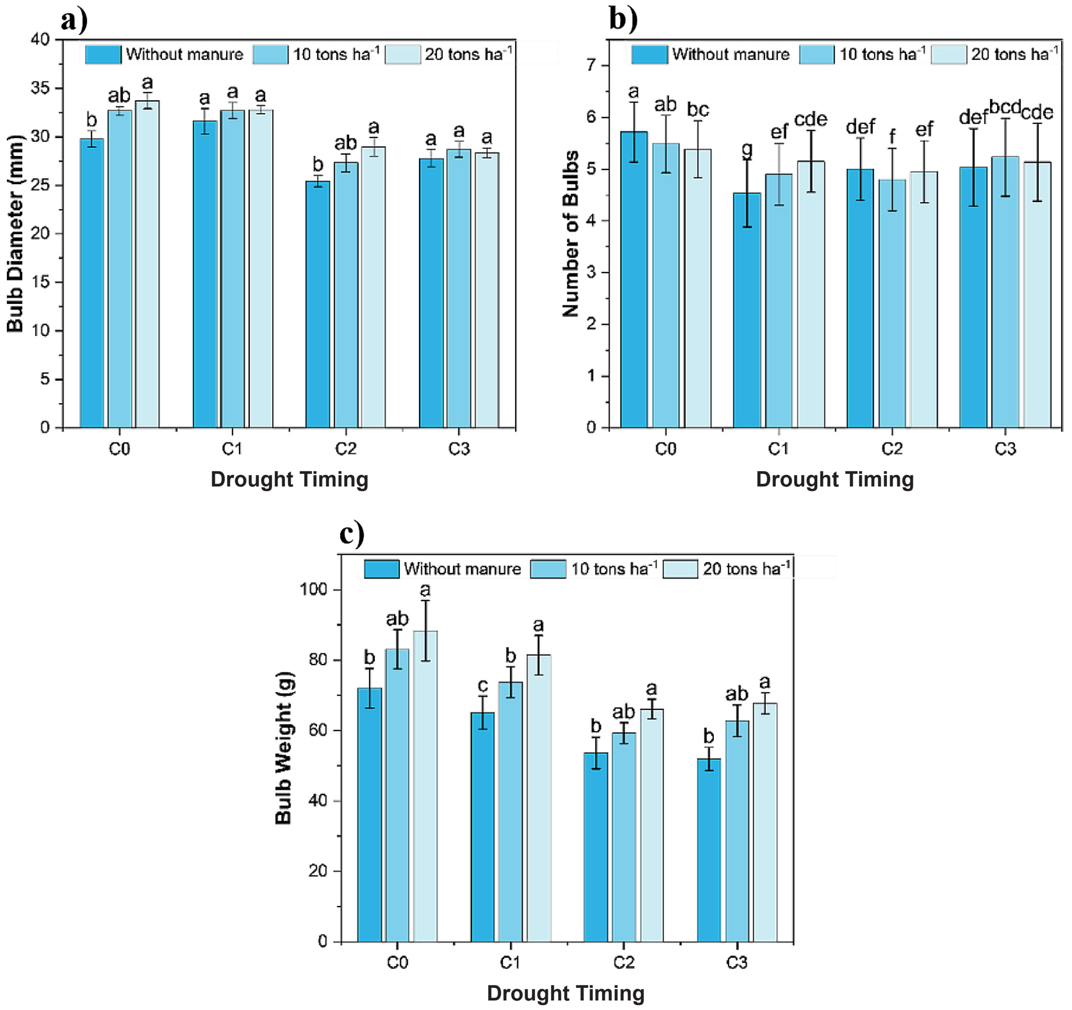

Figure 3. Effects of drought timing (C0 = control; C1 = 1–15 DAP; C2 = 16–30 DAP; C3 = 31–45 DAP) and manure dose (0, 10, 20 t ha^{-1}) on (a) bulb diameter, (b) number of bulbs, and (c) bulb weight of shallot. Bars represent mean ± SD (n = 3). Different letters indicate significant differences (HSD, $p \leq 0.05$)

water deficit reduced production by up to 20.7%, while 20 t ha^{-1} manure use successfully maintained bulb quantity close to optimal conditions with an increase reaching 13.6%. Bulb weight parameters (Figure 3c) demonstrated the highest sensitivity to drought stress, where without manure application, substantial reduction occurred up to 27.9% under stress conditions, whereas with 20 t ha^{-1} manure application, weight increased by up to 30.4%. These findings confirm that manure application consistently improves shallot plant resilience in facing drought stress across all growth stages.

These patterns align with sink physiology in bulbous crops. Drought during bulb initiation and enlargement constrains cell division in the basal plate and parenchyma expansion, and it diverts assimilates to osmoprotection and repair, reducing partitioning to storage tissues (Daryanto et al., 2017; Khokhar, 2017). Because sink priming is time-critical, deficits in these windows impose partially irreversible ceilings on final bulb size even if water returns later, a phenomenon also reported under deficit irrigation regimes (Rop et al., 2016). Manure's stabilizing effects are consistent with enhanced root uptake capacity, improved K nutrition for osmotic regulation and phloem loading, and microbially derived cytokinins that support meristem activity in bulb tissues (Abdelrasheed et al., 2021; Dubey et al., 2021). Practically, this means organic amendment can keep sink development on track despite transient water shortfalls.

The substantial improvement in bulb weight (up to 30.4% increase) with 20 t ha^{-1} manure application demonstrates that bulb biomass accumulation is highly responsive to enhanced water and nutrient availability, particularly during critical bulb formation and enlargement phases. Conversely, the severe bulb weight reduction observed in unfertilized treatments reflects the high vulnerability of storage organs to drought stress, primarily attributed to reduced photosynthetic rates, impaired photoassimilate translocation to developing bulbs, and diminished water and nutrient uptake capacity (Fahad et al., 2017). These findings indicate that organic fertilization represents an effective strategy for maintaining bulb yield under water-limited conditions by improving soil structure and enhancing microbial activity in the rhizosphere.

Observations showed that drought stress significantly impacted the reduction of net assimilation rate (NAR) and relative growth rate (RGR) of shallot plants. The highest reduction occurred

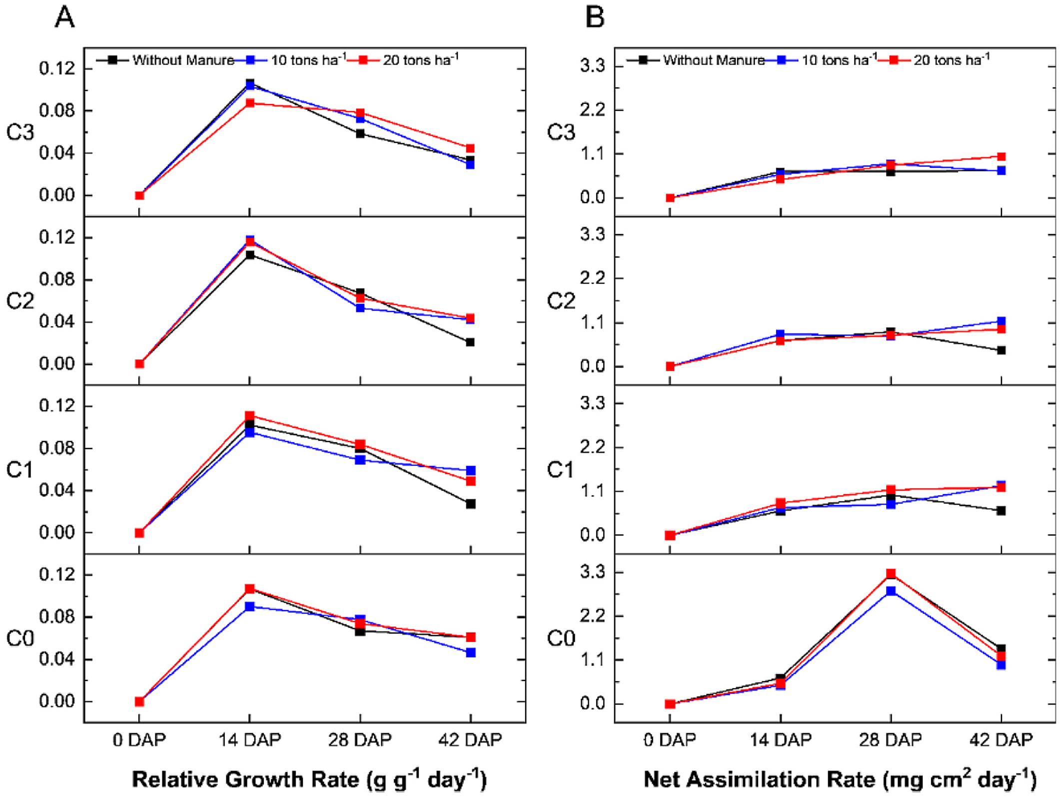

Figure 4. Effects of drought timing (C0 = control; C1 = 1–15 DAP; C2 = 16–30 DAP; C3 = 31–45 DAP) and manure dose (0, 10, 20 t ha^{-1}) on (a) net assimilation rate (NAR) and (b) relative growth rate (RGR) of shallots

when stress was applied during the vegetative phase (C2), while stress during early phase (C1) and bulb formation phase (C3) showed more moderate decreases. Manure increased both NAR and RGR under stress, indicating that improved water and nutrient status translated into higher carbon gain per unit leaf area and faster biomass accrual per unit mass. This corroborates the morphological and biomass results and supports a coherent picture in which organic amendment lifts both source strength and growth efficiency during water-limited periods (Figure 4).

The NAR reduction reflects decreased plant efficiency in performing net photosynthesis per unit leaf area. This is primarily caused by drought-induced stomatal closure, which significantly reduces stomatal conductance and subsequently decreases CO_2 uptake, leading to lower internal CO_2 concentrations that inhibit enzymatic processes essential for photosynthesis (Qiao et al., 2024). Closed stomata inhibit gas exchange and reduce light use efficiency in carbon fixation, directly lowering NAR (Wang et al., 2021). This causes the rate of photosynthesis to decrease, so the rate of accumulation of dry matter of plants decreases. A decrease in NAR can lead to a decrease in RGR. When NARs decline due to photosynthesis disruptions caused by drought stresses, the supply of energy and carbon available to support biomass growth is also reduced. This inhibits physiological processes such as cell division and elongation, so the plant's capacity to increase its size is limited.

High-dose manure application (K2) contributes to increased NAR and RGR by improving soil water retention, enhancing nutrient availability through gradual mineralization, and stimulating microbial populations that produce bioactive compounds such as growth hormones and nutrient-solubilizing enzymes (Dubey et al., 2021). Plants growing in soils with high organic content tend to show better photosynthetic efficiency and growth even under water stress conditions (Abdelrasheed et al., 2021).

Proline content increased under all drought treatments and was highest when stress coincided with bulb formation (C3). Importantly, manure application amplified proline accumulation in a dose-dependent manner, with the 20 t ha^{-1} treatment achieving a ~72% increase over control (Figure 5). As a compatible solute, proline contributes to osmotic adjustment, ROS scavenging, and stabilization of proteins and membranes, thereby preserving metabolic function under dehydration (Ghosh et al., 2022). The stronger proline signal at C3 is consistent with elevated sink demand and high metabolic turnover in enlarging bulbs, which heighten sensitivity to cellular water potential and oxidative load (Dien et al., 2019; Ma et al., 2024).

In contrast, both the early growth phase (C1) and control treatment (C0) exhibited relatively lower proline concentrations, reflecting the differential stress response and recovery capacity across growth stages. Under drought stress conditions, plants synthesize osmoregulatory compounds, including proline, soluble sugars, and betaine, to reduce cellular water potential and enhance water uptake and cellular water retention capacity. However, following rehydration, the concentrations of these osmolytes typically decline as cells require less stringent osmotic regulation to maintain hydration (Abid et al., 2018).

Moreover, manure application appears to facilitate proline biosynthesis by enriching nitrogen availability and enhancing microbial-mediated nutrient cycling, thereby supporting glutamate synthesis, the key precursor of proline (Gai et al., 2020). Comparable findings have been reported in maize and coneflower, where compost and humic acid treatments increased proline levels and improved drought tolerance (Chen et al., 2022; Khorasaninejad et al., 2018). Similarly, (Bokobana et al., 2019) showed that compost-fed maize accumulated more proline, which was associated with higher

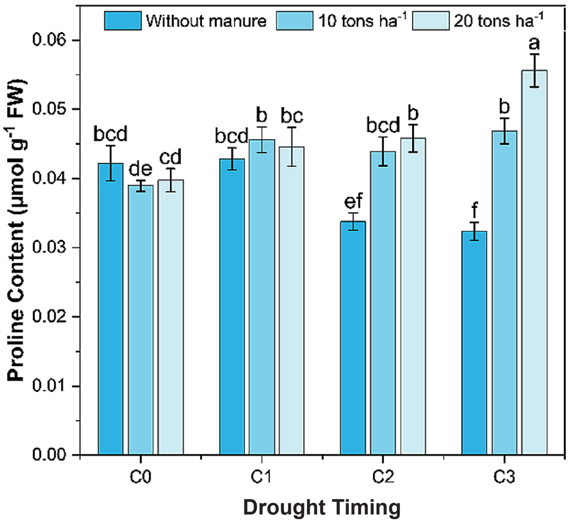

Figure 5. Effects of drought timing (C0 = control; C1 = 1–15 DAP; C2 = 16–30 DAP; C3 = 31–45 DAP) and manure dose (0, 10, 20 t ha^{-1}) on proline content in shallot leaves. Bars represent mean ± SD (n = 3). Different letters indicate significant differences (HSD, $p \leq 0.05$)

antioxidant enzyme activities. These converging results reinforce the interpretation that organic amendments amplify biochemical defense pathways in addition to improving soil water balance.

CONCLUSIONS

This study demonstrated that drought stress significantly limits the growth and yield of shallot (*Allium ascalonicum* L.), with the vegetative phase (16–30 DAP) identified as the most critical window of sensitivity. During this stage, reductions in biomass and leaf area were most pronounced, leading to long-term penalties in yield formation. The application of goat manure consistently mitigated these adverse effects, with 20 t ha^{-1} emerging as the most effective dose. Manure improved soil water retention and nutrient availability, enhanced physiological performance, and reinforced osmotic adjustment, resulting in greater resilience across all drought timings. The findings highlight goat manure as a practical and low-cost strategy for sustaining shallot production in drought-prone systems. Given that results were obtained under semi-controlled conditions, future field-scale validation is essential to assess performance across diverse soils and environments.

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