ISSN 2810-0182 (Online)
ACITYA WISESA: Journal of Multidisciplinary Research
https://journal.jfpublisher.com/index.php/jmr
Vol. 5, Issue 3 (2026)
doi.org/10.56943/jmr.v5i3.1006

Growth and Yield of TSS-Derived Shallot (*Allium cepa* L. var. *aggregatum*) under Varying NPK Mutiara Fertilizer Doses in Lowland Central Java

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ABSTRACT

True Shallot Seed (TSS) presents a viable alternative to conventional bulb-based propagation in shallot cultivation, offering benefits such as lower seed costs, reduced pathogen transmission, and more uniform crop establishment. Nevertheless, TSS-derived plants display distinct physiological and developmental traits that necessitate specific adjustments in nutrient management, particularly concerning inorganic fertilizer application rates. This study was undertaken to examine the growth and yield performance of TSS-grown shallots of the Sanren F1 variety in response to varying doses of NPK Mutiara fertilizer (16:16:16). A field experiment was executed in Bangsri Village, Karangpandan District, Karanganyar Regency, Central Java, Indonesia, over the period from May to August 2025. The trial employed a Randomized Complete Block Design featuring a single treatment factor comprising five NPK Mutiara dosage levels: 0, 75, 150, 225, and 300 kg ha^{-1}*, with each treatment replicated five times. The variables observed included plant height, leaf number, bulb count per plant, fresh bulb weight, and dry bulb weight per plant. Collected data were subjected to analysis of variance at a 95 percent confidence interval, followed by the Honestly Significant Difference test at the 5 percent level whenever significant treatment effects were identified. The results revealed that NPK Mutiara dose significantly influenced plant height, fresh bulb weight, and dry bulb weight, whereas no significant effects were observed on leaf number or bulb number per plant. The application of 75 kg* ha^{-1} *produced increases in fresh and dry bulb weight of approximately 74.9 percent and 77.9 percent, respectively, relative to the unfertilized control, and higher doses did not yield statistically meaningful additional improvements. These outcomes suggest that a dosage of 75 kg* ha^{-1} *NPK Mutiara represents an efficient fertilization benchmark for TSS-based shallot farming in the lowland environments of Central Java.*

Keywords: *Bulb Yield, NPK Mutiara, Nutrient Management, Shallot, True Shallot Seed*

INTRODUCTION

Shallot (*Allium cepa L. var. aggregatum*) is one of the most strategically important horticultural commodities in Indonesia, functioning both as an indispensable culinary spice and as a primary income source for smallholder farmers across the country's major production centers (Rabinowitch, 2021). The crop is cultivated on approximately 145,000 hectares annually, predominantly in Java, which accounts for roughly 75% of national production (Adin et al., 2022). Despite this scale, domestic supply has remained consistently insufficient relative to demand. National shallot consumption rose by 5.12% in 2022 compared to the preceding year, while production declined by 1.11% over the same period, exacerbating an already persistent supply deficit that has repeatedly triggered price volatility in Indonesian food markets (BPS, 2024). Addressing the yield gap in shallot cultivation is therefore a matter of both food security and agricultural economic stability.

Shallot production in Indonesia confronts several overlapping agronomic and structural constraints that limit productivity at the farm level (Sahara et al., 2025). Chief among these is the widespread reliance on vegetative propagation through bulb seeds, which typically constitutes approximately 50% of total production costs and serves as a primary vehicle for the transmission of soilborne and seedborne pathogens (Fadzil et al., 2023). Bulb-based propagation is further hampered by inconsistencies in planting material quality, logistical difficulties in large-scale seed storage and transport, and susceptibility to soilborne diseases such as Fusarium wilt, which has been reported to cause severe crop damage across major shallot-growing regions in Java (Maulidha et al., 2024). Collectively, these constraints reduce both the reliability and the economic efficiency of conventional shallot cultivation systems, underscoring the need for alternative planting technologies.

True Shallot Seed (TSS) represents a technically advanced alternative to bulb-based propagation that has gained increasing recognition in Indonesia over the past decade. TSS refers to botanical seeds of *Allium cepa* var. *aggregatum* produced through sexual reproduction, offering several advantages over vegetative planting material (Annisa et al., 2022; Rabinowitch, 2021). These advantages include a reduction in seed cost of up to ten times compared to conventional bulb seeds, lower risk of pathogen transmission between cropping cycles, more uniform stand establishment, and the potential for considerably higher bulb yield (Adin et al., 2022; Fadzil et al., 2023). Pangestuti et al. (2023) confirmed that vegetative propagation via bulbs inherently promotes pathogen accumulation and diminishes long-term productivity, lending biological justification to the shift toward TSS-based cultivation. The Sanren F1 hybrid variety, one of the commercially available TSS cultivars developed for tropical lowland conditions in Indonesia, has demonstrated consistent performance across diverse agroecological settings and has been associated with high quercetin content, making it agronomically and nutritionally promising (Adin et al., 2022).

Despite its acknowledged advantages, successful TSS cultivation requires specific technical knowledge and precise agronomic management that differ substantially from the practices established for bulb-derived plants. TSS-derived shallots exhibit a distinct phenological trajectory compared to bulb-derived plants, progressing through five principal growth stages including germination, leaf development, tiller formation, bulb initiation, and ripening, each of which has specific environmental and nutritional requirements (Pangestuti et al., 2023). The early seedling phase of TSS-derived plants in particular is characterized by slower root establishment and lower initial vigor compared to bulb-derived transplants, making the crop more sensitive to nutrient availability during this critical window. These physiological differences imply that fertilizer recommendations calibrated for bulb-based systems cannot be directly transferred to TSS-based cultivation without appropriate dose adjustment and field validation.

Nutrient management through balanced NPK fertilization is a central determinant of both vegetative growth and bulb development in shallot production (Solagracya et al., 2025). Nitrogen is required for chlorophyll biosynthesis, protein formation, and the promotion of leaf area expansion, all of which directly influence the photosynthetic capacity of the crop during its vegetative phase. Phosphorus supports adenosine triphosphate-mediated energy transfer and root system development, particularly during early establishment when rapid root growth is essential for water and nutrient uptake. Potassium regulates photosynthate translocation from source to sink tissues and governs osmotic balance in storage organs, processes that are directly linked to bulb enlargement and dry matter accumulation (Atman et al., 2023; Sopha et al., 2021). The synchronized availability of these three macronutrients at appropriate concentrations and timing is therefore critical to achieving optimal shallot yield under field conditions.

Several studies have examined NPK fertilization effects on shallot growth and yield, yet the majority of existing research has focused on bulb-derived rather than TSS-derived plant populations, and findings have consistently shown that fertilizer responses are highly dose- and environment-specific. Atman et al. (2021) reported significant differences in growth and yield among TSS varieties grown in the highlands of West Sumatra under field conditions, indicating that agronomic responses in TSS-based systems are strongly modulated by both genotype and management inputs. The incorporation of NPK fertilizer with lime amendments was shown by Sopha et al. (2021) to significantly improve shallot production under peat soil conditions, further demonstrating the importance of site-specific fertilizer calibration. Pangestuti et al. (2023) additionally noted that TSS-derived shallots follow a phenologically distinct developmental timeline relative to bulb-derived plants, reinforcing the argument that existing nutrient management protocols must be revisited and adapted for TSS-based systems.

NPK Mutiara (16:16:16) is a granular compound fertilizer widely used in Indonesian vegetable production due to its balanced macronutrient composition and ease of field application. In addition to 16% each of nitrogen, phosphate, and potassium, it contains secondary elements including magnesium (0.5% MgO) and calcium (6% CaO), which contribute to overall soil fertility and root health (Hidayatullah et al., 2020). The balanced formulation of NPK Mutiara allows simultaneous delivery of all three primary macronutrients in a single application, reducing labor inputs and ensuring more uniform nutrient distribution across the root zone. However, published data on the appropriate dose of NPK Mutiara specifically for TSS-derived shallots remain scarce. The absence of dose-calibration data for this planting system creates practical uncertainty for farmers transitioning from bulb-based to TSS-based cultivation, as inappropriate fertilizer rates risk limiting yield or increasing production costs without proportional agronomic benefit.

This study was conducted to evaluate the effect of various doses of NPK Mutiara fertilizer on the growth and yield of shallots grown from True Shallot Seed (TSS) of the Sanren F1 variety. The experiment was carried out in Bangsri Village, Karangpandan District, Karanganyar Regency, Central Java, from May to August 2025. The findings are expected to provide evidence-based fertilizer recommendations for NPK Mutiara application in TSS-based shallot cultivation, contributing to more efficient, productive, and economically viable shallot farming systems in Indonesia.

RESEARCH METHODOLOGY

This research was conducted at Bangsri Village, Karangpandan District, Karanganyar Regency, Central Java Province, Indonesia, at an elevation of approximately 200 m above sea level. The experiment was carried out from May to August 2025, covering the complete crop cycle from nursery preparation through to harvest (Montgomey, 2013). The experimental site represents a lowland agroecological condition typical of shallot production areas in Central Java.

The study was arranged in a Randomized Complete Block Design (RCBD) with one treatment factor consisting of five levels of NPK Mutiara fertilizer dose: D0 = 0 kg ha^{-1} (unfertilized control), D1 = 75 kg ha^{-1}, D2 = 150 kg ha^{-1}, D3 = 225 kg ha^{-1}, and D4 = 300 kg ha^{-1}. Each treatment was replicated five times, resulting in 25 experimental units in total. The RCBD was employed to account for soil heterogeneity across the experimental field, thereby ensuring that observed differences in crop response were attributable to the fertilizer treatments rather than to positional variation within the field.

The planting material used was True Shallot Seed (TSS) of the Sanren F1 hybrid variety, which is a commercially released cultivar developed for tropical lowland conditions and recognized for its adaptability and consistent bulb yield. Seeds were raised through a seedling nursery stage prior to field transplanting, following standard TSS cultivation practice. All experimental units received goat manure as a uniform basal organic fertilizer to supply organic matter and support early root development, as well as dolomite as a soil amendment to correct soil acidity and provide supplementary calcium and magnesium. NPK Mutiara fertilizer (16:16:16), which contains 16% nitrogen, 16% phosphate (P_2O_5), 16% potassium (K_2O), 0.5% magnesium oxide, and 6% calcium oxide, was applied at the respective treatment doses as the primary inorganic nutrient source. Pest and disease control was conducted using pesticides applied as required throughout the growing season to minimize yield losses from biotic stresses.

Five agronomic variables were observed at harvest. Plant height was measured in centimetres from the base of the pseudostem to the tip of the longest leaf. The number of leaves per plant and the number of bulbs per plant were recorded by direct counting at the time of harvest. Fresh bulb weight per plant (g plant^{-1}) was measured immediately after harvest before any post-harvest handling, while dry bulb weight per plant (g plant^{-1}) was determined after the harvested bulbs had undergone the standard post-harvest drying process to remove excess moisture, representing the net dry matter accumulation in the storage organs.

All data were subjected to analysis of variance (ANOVA) at a 95% confidence level ($p \leq 0.05$). Where the ANOVA detected a statistically significant treatment effect, mean separation was performed using the Honestly Significant Difference (HSD) test at a 5% significance level. Treatment means followed by the same letter notation were considered not significantly different from one another.

RESULT AND DISCUSSION

Plant Height

Analysis of variance indicated that NPK Mutiara fertilizer dose had a significant effect on the plant height of TSS-derived shallots. Mean plant height values across the five dose levels are presented in Table 1.

Table 1 Mean Plant Height of TSS-derived Shallots at Various NPK Mutiara fertilizer Doses

Treatment	NPK Dose (kg ha^{-1})	Plant Height (cm)	Notation
D0	0	45.6	a
D1	75	45.8	a
D2	150	45.9	a
D3	225	48.2	b
D4	300	49.9	b
HSD 5%		1.89	

Source: Author's Analysis (2025)

Table 1 shows that treatments D3 and D4, corresponding to doses of 225 and 300 kg ha^{-1}, produced plant heights that were significantly greater than those recorded under D0, D1, and D2. This pattern suggests that a minimum threshold of NPK supply, approximately 225 kg ha^{-1} under the conditions of this study, is required before vegetative growth response becomes statistically detectable. Below this threshold, the incremental additions of NPK from 0 to 150 kg ha^{-1} did not produce measurable differences in plant height, indicating that the nutrient demands of TSS-derived shallots during the vegetative phase were only partially met at lower doses.

The positive response of plant height to higher NPK doses is physiologically consistent with the known roles of the three macronutrients in vegetative development. Nitrogen promotes cell elongation and chlorophyll biosynthesis, both of which drive shoot extension, while phosphorus supports root system expansion and the energy transfer processes necessary to sustain active growth. Potassium regulates stomatal function and water use efficiency, contributing to turgor-driven cell expansion throughout the aboveground biomass (Atman et al., 2023; Sopha et al., 2021). The results of the present study are in agreement with those reported by Suddin et al. (2021), who found that increasing doses of NPK 16-16-16 compound fertilizer significantly enhanced shallot plant height up to a specific dose threshold, beyond which no further significant increment was observed. Similarly, Sitorus et al. (2025) reported that NPK fertilization had a significant positive effect on plant height in shallot cultivation, while higher doses beyond the crop requirement did not consistently produce additional vegetative growth. The present findings therefore extend and corroborate those Sitorus et al. (2025) and Suddin et al. (2021) to a TSS-based cultivation system under lowland Central Java conditions, confirming that the dose-dependent pattern of vegetative response to NPK fertilization is consistent across different shallot production systems and planting material types.

Number of Leaves and Number of Bulbs per Plant

The analysis of variance revealed that NPK Mutiara fertilizer dose had no significant effect on either the number of leaves per plant or the number of bulbs per plant in TSS-derived shallots. Both parameters remained relatively stable across all five dose levels, indicating that variation in NPK supply within the range tested did not alter the fundamental morphological architecture of the crop.

This outcome reflects the predominantly genetically determined nature of leaf and bulb number in shallots. In TSS-derived plants, the number of leaves and the potential number of bulbs are largely established during early seedling development and are governed by the intrinsic developmental program of the variety rather than by nutrient availability during the main growing period. Pangestuti et al. (2021) affirmed that in TSS-derived shallots, leaf initiation and bulb primordia formation are determined early in the growth cycle and are relatively insensitive to subsequent variation in inorganic fertilizer application. This finding is consistent with those of Susilawati et al. (2022), who reported that NPK fertilization at varying doses significantly influenced bulb fresh weight and dry weight in shallots but did not significantly affect leaf number or bulb number per plant. Sitorus et al. (2025) similarly observed that macronutrient fertilization had a more pronounced effect on bulb size and weight than on bulb count, reinforcing the view that quantity-related yield parameters are governed primarily by genetic and early physiological factors, while quality-related parameters such as bulb weight and size are more responsive to nutrient management. The present results are therefore consistent with and support those of both Sitorus et al. (2025) and Susilawati et al. (2022), confirming that NPK fertilization in TSS-based shallot systems functions primarily as a driver of yield quality rather than yield quantity in terms of organ number.

Fresh Bulb Weight

NPK Mutiara fertilizer application had a significant effect on fresh bulb weight per plant. Mean fresh bulb weight values across treatment levels are presented in Table 2.

Table 2 Mean Fresh Bulb Weight of TSS-derived Shallots at Various NPK Mutiara Fertilizer Doses

Treatment	NPK Dose (kg ha^{-1})	Fresh Bulb Weight (g plant^{-1})	Notation
D0	0	73.60	a
D1	75	128.60	b
D2	150	143.60	b
D3	225	144.20	b
D4	300	158.40	b
HSD 5%		31.34	

Source: Author’s Analysis (2025)

All fertilized treatments produced significantly higher fresh bulb weights than the unfertilized control. The most notable result is that D1, at only 75 kg ha^{-1}, was already sufficient to increase fresh bulb weight by approximately 74.9% relative to D0, and this improvement was statistically significant. Further increases in NPK dose from 75 to 300 kg ha^{-1} produced a trend of continued improvement in fresh bulb weight, with D4 yielding 158.40 g plant^{-1} compared to 128.60 g plant^{-1} under D1, yet these differences among fertilized treatments were not statistically significant. This pattern points toward a relatively low fertilizer threshold for achieving a substantial yield response in TSS-derived shallots under the conditions of this study, with diminishing statistical returns above 75 kg ha^{-1}.

The significant increase in fresh bulb weight under fertilized conditions reflects the essential roles of nitrogen, phosphorus, and potassium in bulb formation and enlargement. Nitrogen supports biomass accumulation through the synthesis of structural and enzymatic proteins, phosphorus facilitates the energy metabolism underpinning active cell division during bulb development, and potassium drives the translocation of photosynthates from source leaves to the bulb as a primary storage sink (Lasmini et al., 2018; Suddin et al., 2021). The physiological sensitivity of the bulb enlargement phase to nutrient availability in TSS-derived shallots has been emphasized by Tanjung et al. (2022), who noted that adequate nutrient supply during this critical window determines final bulb size rather than bulb number. The pattern observed in the present study, where the first increment of NPK supply produced the largest proportional yield gain, is consistent with the findings of Atman et al. (2023), who reported that NPK fertilization combined with organic inputs significantly improved bulb yield in TSS-based shallot cultivation in West Sumatra. The present study extends these findings by demonstrating that even without organic fertilizer interaction, inorganic NPK Mutiara alone at a relatively modest dose is sufficient to produce substantial and statistically significant improvements in fresh bulb weight in TSS-derived shallots under lowland conditions.

Dry Bulb Weight

Dry bulb weight per plant also responded significantly to NPK Mutiara fertilizer application. Mean dry bulb weight values are presented in Table 3.

Table 3 Mean Dry Bulb Weight Of TSS-Derived Shallots at Various NPK Mutiara fertilizer Doses

Treatment	NPK Dose (kg ha^{-1})	Dry Bulb Weight (g plant^{-1})	Notation
D0	0	59.20	a
D1	75	105.30	b
D2	150	116.36	b
D3	225	116.60	b
D4	300	128.35	b
HSD 5%		31.34	

Source: Author’s Analysis (2025)

All fertilized treatments produced dry bulb weights significantly higher than the unfertilized control. Dry bulb weight represents the net accumulation of structural and storage dry matter in the bulb following the removal of excess water content after post-harvest drying, making it a more precise indicator of productive biomass than fresh weight. The control treatment yielded a mean dry bulb weight of 59.20 g plant^{-1}, while D1 at 75 kg ha^{-1} already produced 105.30 g plant^{-1}, representing an increase of approximately 77.9%. As with fresh bulb weight, further dose increments from D1 to D4 continued to increase dry bulb weight numerically, yet these differences among the fertilized treatments were not statistically significant, confirming that the crop’s nutrient requirements for optimal dry matter accumulation were substantially met at the lowest fertilizer dose tested.

The capacity of NPK fertilization to significantly improve dry bulb weight while leaving bulb number unaffected is consistent with a physiological mechanism in which nutrients predominantly influence the size and dry matter content of individual bulbs rather than the number of bulbs initiated per plant. Potassium in particular plays a central role in regulating the loading and transport of sucrose and other photosynthates into the bulb, governing the rate and extent of dry matter accumulation in storage organs (Sitorus et al., 2025; Susilawati et al., 2022). The observation that dry bulb weight differences among fertilized treatments were statistically indistinguishable despite a numerical difference of approximately 23 g between D1 and D4 suggests that the productivity ceiling achievable through NPK Mutiara fertilization alone under the soil and environmental conditions of the experimental site was reached at the 75 kg ha^{-1} level. This pattern aligns with the principle of diminishing returns in fertilizer response curves and supports the recommendation that excessive fertilizer doses above the crop requirement do not provide commensurate agronomic benefit.

Taken together, the findings of this study both support and extend the body of existing literature on shallot NPK fertilization, while offering new information that is specific to TSS-based cultivation systems. The significant effects of NPK Mutiara on plant height, fresh bulb weight, and dry bulb weight observed here are directly consistent with the conclusions of Sitorus et al. (2025) and Suddin et al. (2021), both of whom reported that compound NPK fertilization at 16-16-16 formulations significantly improved shallot growth and yield components. However, the present study diverges from those conducted on bulb-derived shallots in one important respect: the effective dose threshold observed here, at 75 kg ha^{-1}, is considerably lower than the doses commonly recommended for bulb-based systems, which typically range from 200 to 600 kg ha^{-1} (Sitorus et al., 2025; Suddin et al., 2021). This suggests that TSS-derived shallots of the Sanren F1 variety under lowland Central Java conditions may be more nutrient-use efficient than bulb-derived populations, a finding with direct practical significance for reducing production costs in TSS-based cultivation.

The finding that leaf number and bulb number per plant were unaffected by NPK dose is consistent with and further confirms the conclusions of Pangestuti et al. (2023) and Susilawati et al. (2022), both of whom reported that structural parameters determined during early crop development are relatively insensitive to inorganic fertilizer variation. This study therefore contributes confirmatory evidence for the TSS context specifically, which had not been thoroughly addressed in the earlier literature focused on bulb-derived shallots. By demonstrating that the same nutrient insensitivity of morphological parameters documented in bulb-based systems also applies to TSS-derived plants under field conditions, the present study strengthens the generalizability of this conclusion across shallot cultivation systems.

Furthermore, the present study directly connects to and substantiates the research gap identified by Adin et al. (2022) and Fadzil et al. (2023) in the Introduction, both of whom noted that agronomic management for TSS-based systems, including fertilizer calibration, requires dedicated field research. The results presented here provide the first empirical evidence of NPK Mutiara dose response specifically for Sanren F1 TSS-derived shallots under lowland Central Java conditions, filling this identified gap with site-specific and variety-specific data that can serve as an agronomic baseline for future TSS cultivation research and extension recommendations in similar agroecological environments.

CONCLUSION

This study demonstrated that NPK Mutiara fertilizer application at varying doses significantly influenced the growth and yield components of shallots derived from True Shallot Seed (TSS) of the Sanren F1 variety under lowland conditions in Karanganyar, Central Java. Specifically, plant height, fresh bulb weight, and dry bulb weight responded significantly to fertilizer treatment, while the number of leaves and number of bulbs per plant remained unaffected across all dose levels. These results confirm that NPK fertilization in TSS-based shallot cultivation functions primarily as a driver of bulb size and dry matter accumulation rather than of organ number, which is governed more strongly by the genetic characteristics of the variety and by physiological processes established during early seedling development.

The dose of 75 kg ha^{-1} NPK Mutiara was sufficient to produce a statistically significant improvement in both fresh and dry bulb weight relative to the unfertilized control, with increases of approximately 74.9% and 77.9%, respectively. Higher doses up to 300 kg ha^{-1} continued to show a positive numerical trend in yield components but did not produce statistically significant additional gains beyond the 75 kg ha^{-1} level. This pattern indicates that the nutrient requirements of TSS-derived Sanren F1 shallots for optimal bulb yield under the conditions of this study were substantially met at the lowest dose tested, suggesting a notably lower fertilizer threshold compared to conventional bulb-based systems.

Based on these findings, a dose of 75 kg ha^{-1} NPK Mutiara is recommended as an efficient and economically viable fertilization strategy for TSS-based shallot cultivation under similar agroecological conditions. Future research should examine the interaction between NPK Mutiara dose and other management factors including plant spacing, organic fertilizer type, and irrigation regime, as well as test this recommendation across multiple growing seasons and diverse soil types to confirm its broader applicability for TSS-based shallot production in Indonesia.

ACKNOWLEDGEMENT

The authors express their sincere gratitude to the Board of the Higher Education Foundation and the Rector of Universitas Slamet Riyadi Surakarta for providing financial support for this research, as well as to the Head of the Institute for Research and Community Service (LPPM) of Universitas Slamet Riyadi for the guidance and assistance rendered throughout the implementation of this study.

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