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Research Article

Growth, yield, and nitrogen use efficiency of shallots with plant growth-promoting rhizobacteria and cattle manure

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ABSTRACT

Continuous and excessive application of inorganic-N fertilizer leads to accumulation of chemical residues in soils, as plants typically utilize only about 50% of the applied nitrogen, which can further lead to environmental pollution. Resolve the low nitrogen uptake and fertilizer use efficiency, organic amendments, and beneficial microorganisms provide viable alternatives. The objective of this research was to evaluate the effects of different PGPR concentrations and cattle manure doses on nitrogen uptake dynamics and nitrogen use efficiency parameters (NUpE, NUtE, and NUE), as well as shallot growth and yield, to determine the most efficient treatment that supports nutrient efficiency and sustainable agronomic practices. The experiment used a constant nitrogen inorganic fertilizer of 100 kg ha^{-1}. A factorial randomized block design was employed, consisting of four PGPR concentrations: 0, 10, 20, and 30 mL L^{-1}. The second factor was cattle manure dosage consisted of 0, 10, and 30 ton ha^{-1}. Observation variables included plant growth, yield components, nitrogen uptake dynamics, nitrogen uptake efficiency (NUpE), nitrogen utilization efficiency (NUtE), and nitrogen use efficiency (NUE). The results indicated significant interactions between PGPR and cattle manure in the number of tillers at 8 weeks after planting (WAP), crop growth rate (CGR) at 6–8 WAP, chlorophyll index, fresh and dry weight, and bulb weight. The treatment combining 30 mL L^{-1} PGPR with 30 t ha^{-1} cattle manure significantly increased average bulb weight by 136.6% compared to without PGPR + without cattle manure. This treatment also achieved the highest nitrogen uptake across all growth stages, peaking at 1 kg ha^{-1} per day at 56 DAP and recorded the highest NUpE from 41.90% to 64.50%, and reduced soil nitrogen losses by 22.6%. Consistent improvements in NUpE, NUtE, and NUE indicate that this integration enhances nitrogen translocation into shallot bulbs, leading to more efficient nutrient use, supporting higher productivity, and sustainable nutrient management.

Keywords: *Allium ascalonicum*; NUE; NUpE; NUtE; organic fertilizer

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INTRODUCTION

Nitrogen is an essential nutrient that plays a vital role in vegetative growth and shallot bulb production. Nitrogen requirements are generally met through inorganic fertilizers. However, excessive use of inorganic fertilizers might cause water pollution because plants only absorb about 50% of the nitrogen, as stated in previous research, that approximately 50% of the 100-120 kg N ha^{-1} typically applied to shallot fields is leached (De Visser, 1998). Inorganic fertilization can be harmful, especially at high nitrogen fertilization rates, as it causes increased nitrogen loss in the form of greenhouse gas N_2O and a decline in the physical, chemical, and biological properties of the soil (Dincă et al., 2022). Increasing nitrogen application from 100 to 500 kg ha^{-1} caused a decrease in nitrogen use efficiency by 80% (Lukman & Sopha, 2014).

This follow-up study examines nitrogen use efficiency in shallots (*Allium ascalonicum* L.) after earlier research on reducing inorganic nitrogen fertilizer doses using cattle manure and PGPR. Previous studies reported that combining reduced inorganic nitrogen (112.5 kg N from Urea + 37.5 kg N from ZA) with 2.5 t ha^{-1} cattle manure and 20 mL L^{-1} PGPR reduced inorganic nitrogen use by 50 kg N ha^{-1} compared with the conventional 150 kg N from Urea + 50 kg N from ZA (Marpaung & Maghfoer, 2023). However, key gaps remain: the nitrogen absorbed by plants cannot be accurately measured, the amount taken up and translocated to shallot bulbs is unknown, and the overall nitrogen use efficiency cannot be determined.

Common concerns connected with the use of inorganic fertilizer include decreased crop productivity, low soil organic matter content, low fertilizer use efficiency, also nutrient imbalance between additions and removals from the soil (Bhatt et al., 2019). Soils treated with inorganic NPK fertilizer showed a lower microbial biomass (18.5 μg g^{-1} soil dry weight) compared to those treated with manure, which had a microbial biomass of 22.6 μg g^{-1} soil dry weight (Lazcano et al., 2013). The short root system of shallots limits nitrogen uptake efficiency, increasing nitrogen losses through volatilization and leaching; this can be mitigated by PGPR, which mineralizes organic nitrogen into plant-available forms such as ammonia (NH_3^-) or ammonium ions (NH_4^+), and can be absorbed by plants through the deamination process by PGPR bacteria such as *Pseudomonas* and *Bacillus* (Bhattacharyya & Jha, 2012).

PGPR constitute a beneficial microorganism, where they interact closely with roots, and inhabit the soil rhizosphere (area around plant roots) (Bhattacharyya & Jha, 2012). PGPR can also increase nutrient uptake efficiency by increasing nutrient availability for the plant and thereby reducing dependence on inorganic fertilizers (Safdar et al., 2022; Tuhuteru et al., 2019). The organic matter in cattle manure increases soil microbial activity by providing an energy source for soil microorganisms. Adding organic matter can boost soil porosity, providing more space for water and air, which helps microorganisms access the oxygen needed for decomposition (Soumare et al., 2020). Nitrogen use efficiency (NUE) is widely acknowledged as an important parameter for optimizing nitrogen use in sustainable agricultural systems (Mohammadi et al., 2013). Controlled-release nitrogen fertilizers release nitrogen more gradually, greatly enhancing nitrogen uptake and decreasing nitrogen losses (Koocheki & Seyyedi, 2015).

The objective of this research was to evaluate the influence of PGPR concentrations and cattle manure doses on the growth and yield of shallot, nitrogen uptake dynamics, and nitrogen use efficiency parameters (NUpE, NUtE, and NUE). Using a field experiment with the recommended nitrogen application rate of 100 kg N ha^{-1} supplied as urea fertilizer. This research highlights the most effective PGPR and cattle manure interaction for maximizing nutrient uptake and crop productivity, providing a meaningful contribution to nutrient efficiency and sustainable agronomic management.

MATERIALS AND METHODS

The experiment was implemented from May to June 2025 at Kasin Village, Ampeldento, Karang Ploso District, Malang Regency, East Java. The study site was situated at an altitude of 615 meters above sea level, with an average relative humidity of 83%, temperature fluctuations between 20 °C and 30 °C, and a mean monthly rainfall of 214.6 mm. Initial soil analysis showed a pH of 7.1 (H_2O) and 6.3 (KCl), with 1.53% organic C, 0.16% total N, and a C/N ratio of 10. The analysis was conducted at the Soil Laboratory, Faculty of Agriculture, Brawijaya University.

The materials used were insecticides, fungicides, Super Philip variety shallot seeds, organic cattle manure, Mupus PGPR consisting of *Bacillus* sp. (1 × 10^8 CFU mL^{-1}), *Pseudomonas* sp. (1 × 10^8 CFU mL^{-1}), *Azotobacter* sp. (1 × 10^8 CFU mL^{-1}), and *Azospirillum* sp. (1 × 10^8 CFU mL^{-1}), and basic fertilizers, particularly urea, SP36, and KCl. The tools used in this study included a Leaf Area Meter (LiCor 3100c), oven (Memmert type 21937 FNR), analytical balance (PS 1200), and a SPAD (Minolta 502).

The research employed a factorial randomized block design involving two factors. The first factor was PGPR concentration at 0, 10, 20, and 30 mL L^{-1}. The second factor was cattle manure doses consisted of 0, 10, and 30 ton ha^{-1}. Each treatment combination was repeated three times, totaling 36 experimental units.

Experimental plots covered a width of 2.25 m x 1 m in length. The spacing between treatments was 50 cm, and the spacing between replicates was 1 m. Planted seedlings were cleaned of dirt and dried tuber skin. To accelerate shoot growth, the tuber tips were cut into quarters. Cattle manure was applied 7 days before planting. The inter-plant distance was 20 cm x 15 cm (Biru, 2015).

PGPR is applied by spraying onto the plant's root zone using a sprayer three times: at planting, 1 WAP, and 2 WAP with 10 mL per plant. Plant maintenance included watering, replanting, pest and disease management, and lastly weeding. Nitrogen fertilization was utilized at a uniform rate in each experimental plot to evaluate N nutrient uptake efficiency across varying manure and PGPR doses. The recommended nitrogen rate for shallots is 100 kg N ha^{-1} (Gebretsadik & Dechassa, 2018). Shallots were harvested at 59 days after planting. Ready-to-harvest shallots were characterized by yellowing (70%) and drying leaves, a red bulb at its maximum size, and softening of the leaf base and stem.

Observation variables included growth parameters (which are plant height, leaf area, number of tillers, and CGR), yield parameters (chlorophyll index, shallots' fresh weight and dry weight, bulb weight), along with nitrogen efficiency (nitrogen uptake, NUpE, NUtE, and NUE).

Leaf area of shallots was measured destructively using a leaf area meter. Since shallot leaves have a cylindrical morphology, they were cut longitudinally before measurement.

Crop Growth Rate (CGR) was used to determine the increase in plant dry matter per unit land area and time. CGR was expressed as g m^{-2} per day and determined with the formula (Gul et al., 2013):

$$CGR = \frac{W2-W1}{T2-T1} \times \frac{1}{GA}$$

where W1 = initial weight, W2 = final weight, T1= time at the start of the period, T2 = time at the end of the period, and GA = ground area (m^2).

Chlorophyll index was measured using a hand-held SPAD directly in the field by positioning the SPAD sensor at the basal, middle, and apical portions of three leaves per clump. Three clumps were selected as samples for each treatment.

Nitrogen content analysis was conducted on the entire shallot plants, utilizing dried samples obtained from 12 treatment plots. These samples were subsequently examined at 14, 28, 42, and 56 days after planting (DAP). The nitrogen content in plant samples was measured using the Kjeldahl method, with analysis conducted at the Soil Laboratory, Faculty of Agriculture, Brawijaya University. The calculation for nitrogen uptake is based on this formula (Congreves et al., 2021):

$$\text{Nitrogen uptake (kg ha}^{-1}\text{ per day)} = \text{Plant dry weight} \times \text{Plant N concentration}$$

Nitrogen uptake efficiency (NUpE) was calculated using the formula given below (Simelane et al., 2023):

$$\text{NUpE (\%)} = \frac{\text{(plant dry weight} \times \text{population} \times \text{plant N)}}{\text{Total N applied}}$$

Nitrogen utilization efficiency (NUtE) was calculated using the following formula (Simelane et al., 2023):

$$\text{NUtE (\%)} = \frac{\text{Harvested yield}}{\text{(plant dry weight} \times \text{population} \times \text{plant N)}}$$

Nitrogen use efficiency (NUE) was determined using the following formula (Simelane et al., 2023):

$$\text{NUE (\%)} = \text{NUpE} \times \text{NUtE}$$

Research data were analyzed using ANOVA (F test) at a 5% significance level, with the Honestly Significant Difference (HSD) test applied if significant effects were found. Statistical analyses were performed using DSAASTAT version 1.514.

RESULTS AND DISCUSSION

Plant growth

Analysis of plant height variance showed no interaction between PGPR concentration and cattle manure dose on plant height and leaf area variables at 8 WAP (Table 1). The highest plant height and leaf area were observed with 30 mL L^{-1} PGPR and 30 t ha^{-1} cattle manure.

Table 1. The average height of shallot plants and leaf area at 8 WAP PGPR concentrations and cattle manure dosages.

Treatment	Plant height (cm)	Leaf area (mm^2 per clump)
PGPR (mL L^{-1})		
0	38.10b	532.0b
10	39.72ab	596.6ab
20	41.38ab	631.4a
30	45.37a	649.6a
HSD 5%	6.47	95.38
Cattle manure (t ha^{-1})		
0	37.88b	572.7b
10	40.96ab	559.4b
30	44.60a	675.1a
HSD 5 %	5.07	74.72
CV (%)	12.01	12.09

Note: Means followed by the same letter reveal the treatments did not differ significantly at the 5% level HSD test; cv = coefficient of variation.

At 8 weeks after planting, 30 mL L^{-1} PGPR increased plant height by 19.08% compared to no PGPR. Meanwhile, 30 t ha^{-1} cattle manure significantly increased plant height compared to no manure. Cow manure increases soil N availability and plant uptake (≈11–12%), while the rest enriches soil microbes that enhance nutrient accumulation and root growth (Zhao et al., 2022). The leaf area data show that 30 mL L^{-1} PGPR increased leaf area by 22.10% compared with no PGPR and by 8.88% compared with 10 mL L^{-1} PGPR. Meanwhile, 30 t ha^{-1} cattle manure increased leaf area by 17.8% compared with no manure. The growth enhancement mechanisms carried out by PGPR, such as hormone regulation, increased nutrient absorption (Brar et al., 2019), and nutrient supply from cow manure, such as nitrogen, phosphorus, and potassium (Tawakal et al., 2025), additively and independently influence leaf area.

Table 2 shows that PGPR concentration and cattle manure dosage interactively affected the number of tillers at 8 WAP, coinciding with the advanced vegetative phase, where nutrient availability from optimally decomposed organic fertilizers began to become apparent, while the PGPR population had stabilized in the rhizosphere (Triharyanto et al., 2021). This aligns with research by Ng. Lende et al. (2020) found an interaction between treatments on the number of tillers at 10 WAP. The treatment involved applying 10 t ha^{-1} of chicken manure along with 20 mL L^{-1} of *Pseudomonas fluorescens* inoculum, resulting in 291.70 tubers per plot.

Table 2. The influence of an interaction between PGPR concentrations and cattle manure dosages on tiller number at 8 WAP.

Treatment	Tiller number		
PGPR (mL L^{-1})	CM 0 t ha^{-1}	CM 10 t ha^{-1}	CM 30 t ha^{-1}
0	7.22a	7.11a	8.66a
	A	A	A
10	7.11a	9.77ab	8.22b
	A	AB	A
20	7.55a	9.11ab	10.44b
	A	B	A
30	7.55a	10.11ab	10.66b
	A	B	A
HSD 5% - interaction	2.57		
CV (%)	10.03		

Note: Capital letters in one column indicate the effect of cattle manure doses at each PGPR concentration; lowercase letters in one row indicate the effect of PGPR concentrations at each level of cattle manure. Values followed by the same letter in the same column or row are not significantly different according to the HSD test at the 5% level; CV = coefficient of variation. CM-cattle manure

Table 3. The influence of an interaction between PGPR concentrations and cattle manure dosages on CGR at 6-8 WAP.

Treatment	CGR 6-8 WAP (g m^{-2} per day)		
PGPR (mL L^{-1})	CM 0 t ha^{-1}	CM 10 t ha^{-1}	CM 30 t ha^{-1}
0	0.460a	0.75a	0.488a
	A	A	A
10	0.461a	0.742a	0.685a
	A	A	AB
20	0.532a	0.659a	1.220b
	A	A	BC
30	0.702a	1.137ab	1.365b
	A	A	C
HSD 5% - interaction	0.54		
CV (%)	23.82		

Note: Capital letters in one column indicate the effect of cattle manure doses at each PGPR concentration; lowercase letters in one row indicate the effect of PGPR concentrations at each level of cattle manure. Values followed by the same letter in the same column or row are not significantly different according to the HSD test at the 5% level; CV = coefficient of variation; CM-cattle manure

Table 3 shows that PGPR and cattle manure interaction affected CGR at 6–8 WAP, where 30 mL L^{-1} PGPR + 30 t ha^{-1} manure increased CGR by 196.7% compared to the control. This is in line with research by Gallart et al. (2021), which reported that 50% urea + 50% cow manure + PGPR increased total biomass by 32% and fine root biomass by 19% after PGPR inoculation. Increased nutrient availability from organic matter decomposition will align with PGPR colonization in the rhizosphere, resulting in synergy in improving nutrient uptake and plant photosynthetic efficiency (Zhang et al., 2020).

Yield components

Analysis of variance showed an interaction between the concentration of shallots and cattle manure on the chlorophyll index, plant fresh weight, plant dry weight, and bulb weight. The first yield component evaluated was the chlorophyll index. As shown in Table 4, a significant interaction between PGPR concentration and cattle manure doses was observed. The combined application of 30 mL L^{-1} PGPR and 30 t ha^{-1} cattle manure resulted in the highest chlorophyll index, representing a 46.61% increase compared with the control treatment. This interaction indicates that the positive effect on chlorophyll accumulation was maximized when both biological and organic inputs were applied together. High microbial activity accelerates the release of nutrient compounds for plant absorption and the decay of organic amendments. Various factors, including light, carbohydrates, temperature, genetic factors, and nitrogen availability, influence chlorophyll biosynthesis (Zhao et al., 2022). Nitrogen plays an important role in leaf growth and production. Adequate nitrogen availability can enhance chlorophyll biosynthesis, leaf organ formation, and assimilation processes (Purbajanti et al., 2019).

Table 4. Interaction between PGPR concentrations and cattle manure dosages on the chlorophyll index

Treatment	Chlorophyll index		
PGPR (mL L^{-1})	CM 0 t ha^{-1}	CM 10 t ha^{-1}	CM 30 t ha^{-1}
0	35.93a	32.91a	37.77a
	A	A	A
10	39.24a	36.15a	39.14a
	A	A	AB
20	34.19a	37.99a	46.95a
	A	A	AB
30	32.99a	43.24ab	52.68b
	A	A	B
HSD 5%	14.16		
CV (%)	12.19		

Note: Capital letters in one column indicate the effect of cattle manure doses at each PGPR concentration; lowercase letters in one row indicate the effect of PGPR concentrations at each level of cattle manure. Values followed by the same letter in the same column or row are not significantly different according to the HSD test at the 5% level; CV = coefficient of variation; CM-cattle manure

Table 5 shows that the concentration of 30 mL L^{-1} PGPR + dose of 30 t ha^{-1} cattle manure was significantly different and gave an average increase in plant fresh weight of 69.83% compared to without PGPR + without cattle manure, an average increase in plant fresh weight of 19.69% compared to the treatment of 30 mL L^{-1} PGPR + without cattle manure, and an average increase in plant fresh weight of 59.33% compared to the treatment without PGPR + cattle manure 30 t ha^{-1}.

Table 5. Interaction between PGPR concentrations and cattle manure dosages on plant fresh weight.

Treatment	Plant fresh weight (g $clump^{-1}$)		
PGPR (mL L^{-1})	CM 0 t ha^{-1}	CM 10 t ha^{-1}	CM 30 t ha^{-1}
0	99.02a	96.44a	105.5a
	A	A	A
10	113.2a	121.2a	98.62a
	A	AB	A
20	109.1a	141.2ab	161.5b
	A	AB	B
30	140.5a	147.7a	168.1a
	A	B	B
HSD 5%	47.03		
CV (%)	12.64		

Note: Capital letters in one column indicate the effect of cattle manure doses at each PGPR concentration; lowercase letters in one row indicate the effect of PGPR concentrations at each level of cattle manure. Values followed by the same letter in the same column or row are not significantly different according to the HSD test at the 5% level; CV = coefficient of variation; CM-cattle manure

Table 6 shows that interaction was also seen in the plant dry weight variable, with an average increase of 72.02% in the treatment PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure compared with the control treatment, which is without PGPR and without cattle manure. The average dry weight increased 19.68% compared to the treatment of 30 mL L^{-1} PGPR + without cattle manure. The increase in the dose from 0 to 25 t $ha^{-1,}$ providing shallots highest fresh weight at 21,900 kg ha^{-1} and shallots highest dry weight at 9,650 kg ha^{-1} (Atman et al., 2021). Increasing the dose of cattle manure gave significant outcomes on the fresh weight and dry weight of shallots. Other studies reported that an optimal dose of 20 t ha^{-1} manure of + 20 mL L^{-1} PGPR produced the highest fresh weight (45.93 g) and the highest dry weight (4.99 g). This treatment was also able to maintain fresh weight (36.98 g) and dry weight (3.40 g) under salinity stress conditions (Kurniawan et al., 2025).

Table 6. Interaction between PGPR concentrations and cattle manure dosages on plant dry weight and bulb weight of shallots.

Treatment	Plant dry weight (g per clump)		
PGPR (mL L^{-1})	CM 0 t ha^{-1}	CM 10 t ha^{-1}	CM 30 t ha^{-1}
0	48.88a	48.22a	52.77a
	A	A	A
10	56.6a	63.71a	49.31a
	A	AB	A
20	54.57a	70.61a	78.74a
	A	AB	B
30	70.25a	73.88a	84.08a
	A	B	B
HSD 5% - interaction		24.61	
CV (%)		13.22	
		Total bulb weight (g per plot)	
0	27.88a	28.14a	30.67a
	A	A	A
10	32.42a	37.23a	31.57a
	A	AB	A
20	33.13a	42.72ab	51.98b
	A	AB	B
30	41.95a	48.88ab	65.95b
	A	B	B
HSD 5% - interaction		17.69	
CV (%)		15.11	

Note: Capital letters in one column indicate the effect of cattle manure doses at each PGPR concentration; lowercase letters in one row indicate the effect of PGPR concentrations at each level of cattle manure. Values followed by the same letter in the same column or row are not significantly different according to the HSD test at the 5% level; CV = coefficient of variation; CM-cattle manure

Treatment of PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure resulted in a higher average bulb weight compared to other treatments (Table 6). The integration of PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure was significantly different. It increased the average bulb weight by 136.6% compared to the treatment without PGPR + without cattle manure, by 57.27% compared to the treatment with 30 mL L^{-1} PGPR + without cattle manure, and by 115.03% compared to the treatment without PGPR + 30 t ha^{-1} cattle manure. In general, manure application increases crop yields by an average of 7.6% compared to mineral fertilizers. A greater yield increase occurs with long-term application (>10 years), at 27.7% (Du et al., 2022).

Nitrogen efficiency analysis

Nitrogen uptake measurements in shallots were conducted at 14, 28, 42, and 56 days after planting (DAP). This data illustrates the dynamics of nitrogen uptake by the plants throughout the growth period, from the early vegetative phase to near bulb maturity. Increases in nitrogen uptake values over time indicate the accumulation of nutrients absorbed by the plants, while changes in uptake rates between observation periods reflect nutrient requirements at each growth phase (Gong et al., 2020).

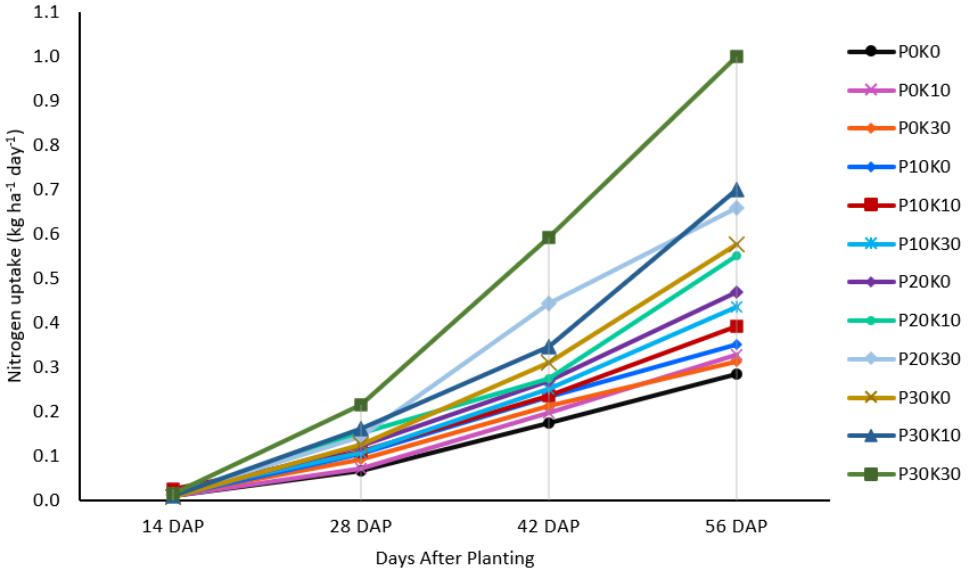

Figure 1. Nitrogen uptake of shallots at various PGPR concentrations and cattle manure doses at 14, 28, 42, and 56 days after planting. Treatments consisted of twelve combinations of PGPR concentrations and cattle manure doses: P0K0 (no PGPR + no cattle manure); P0K10 (no PGPR + 10 t ha^{-1} cattle manure); P0K30 (no PGPR + 30 t ha^{-1} cattle manure); P10K0 (PGPR 10 mL L^{-1} + no cattle manure); P10K10 (PGPR 10 mL L^{-1} + 10 t ha^{-1} cattle manure); P10K30 (PGPR 10 mL L^{-1} + 30 t ha^{-1} cattle manure); P20K0 (PGPR 20 mL L^{-1} + no cattle manure); P20K10 (PGPR 20 mL L^{-1} + 10 t ha^{-1} cattle manure); P20K30 (PGPR 20 mL L^{-1} + 30 t ha^{-1} cattle manure); P30K0 (PGPR 30 mL L^{-1} + no cattle manure); P30K10 (PGPR 30 mL L^{-1} + 10 t ha^{-1} cattle manure); and P30K30 (PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure).

The shallot nitrogen uptake pattern entered an exponential phase at 14 days after planting, characterized by slow growth as the plants adapted to the environment. At 28-42 days after planting, the shallots entered a linear phase, during which vegetative growth was optimal and constant. Nitrogen uptake increased sharply because the shallots needed nitrogen for leaf and bulb growth. At 56 days after planting, the growth rate was maximum, as the shallots entered the senescence/stationary phase, marked by yellowing leaves and readiness for harvest. Figure 1 shows that nitrogen uptake was lowest in the treatment without PGPR and without cattle manure (P0K0), with only 0.285 kg ha^{-1} day^{-1} at 14 DAP, indicating limited nitrogen absorption. In contrast, the treatment with PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure (P30K30) recorded the highest uptake at all plant ages, reaching 1 kg ha^{-1} day^{-1}. This represents an increase of 250.88% compared to P0K0, 72.9% compared to P30K0, and 221.54% compared to P0K30. The results indicate that higher PGPR concentrations combined with cattle manure doses enhance nitrogen uptake efficiency in shallots. High PGPR concentration without cattle manure reduced nitrogen uptake by 42.2% (P30K0), indicating that PGPR requires organic substrates from manure for nutrients, energy, and carbon (Gallart et al., 2021).

Nitrogen accumulation at maximum uptake time generally ranges between 1.5 - 3.0 kg ha^{-1} per day (Geisseler et al., 2022). Similarly, high manure doses without PGPR decreased uptake by 68.9% (P0K30). In contrast, the combination of PGPR and cattle manure enhanced root growth, hormone production (IAA, GA), and enzyme activity, thereby accelerating organic N mineralization and nitrification (Paungfoo-Lonhienne et al., 2019). This synergy reduced N losses, increased uptake during the vegetative phase, and resulted in significantly higher total N accumulation in shallots (43.03 kg N ha^{-1}) under integrated organic–inorganic fertilization (de Jesus et al., 2023).

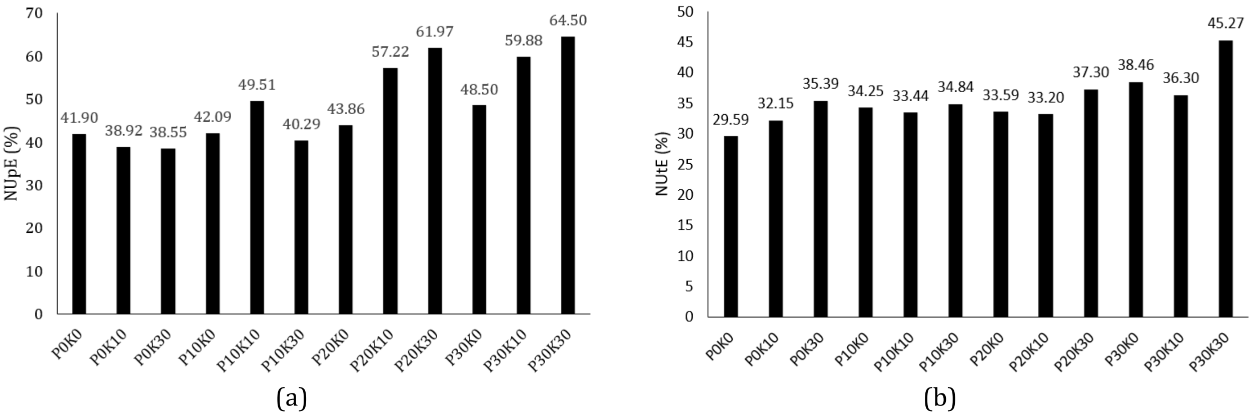

Figure 2. Effects of PGPR concentrations and cattle manure doses on (a) nitrogen uptake efficiency (NUpE) and (b) nitrogen utilization efficiency (NUtE) of shallots. Treatments consisted of twelve combinations of PGPR concentrations and cattle manure doses; P0K0 (no PGPR + no cattle manure); P0K10 (no PGPR + 10 t ha^{-1} cattle manure), P0K30 (no PGPR + 30 t ha^{-1} cattle manure), P10K0 (PGPR 10 mL L^{-1} + no cattle manure), P10K10 (PGPR 10 mL L^{-1} + 10 t ha^{-1} cattle manure), P10K30 (PGPR 10 mL L^{-1} + 30 t ha^{-1} cattle manure), P20K0 (PGPR 20 mL L^{-1} + no cattle manure), P20K10 (PGPR 20 mL L^{-1} + 10 t ha^{-1} cattle manure), P20K30 (PGPR 20 mL L^{-1} + 30 t ha^{-1} cattle manure), P30K0 (PGPR 30 mL L^{-1} + no cattle manure), P30K10 (PGPR 30 mL L^{-1} + 10 t ha^{-1} cattle manure), and P30K30 (PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure).

The highest NUpE value (64.50 %) was obtained with P30K30 (PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure), showing that half of the applied inorganic N (Nitrogen 100 kg ha^{-1}) was absorbed. In contrast, the lowest (38.55 %) was observed in P0K30 (Figure 2). Both increasing PGPR concentrations and manure doses generally enhanced NUpE, with the best results from P30K30, P20K30, and P30K10. The NUpE value increases because the diazotrophic PGPR increases N_2 fixation and converts organic nitrogen into absorbable NH_4^+ and NO_3^- (Gunes et al., 2015). Other research also indicates that adding PGPR to soil fertilized with a 50% organic and 50% conventional inorganic fertilizer composition can increase kikuyu grass (*Pennisetum clandestinum*) growth, with yields equivalent to those with 100% conventional inorganic fertilizer. Furthermore, this combination also reduces mineral N leaching by up to 95% compared to treatments using entirely inorganic fertilizers (Paungfoo-Lonhienne et al., 2019).

Figure 2 showed that the highest NUtE value (45.27 %) was also recorded in P30K30, followed by P30K0 (38.46 %) and P20K30 (37.30 %). This proves that PGPR and cattle manure treatments can increase nitrogen allocation from shallot bulbs through indirect mechanisms, such as the fact that shallots have a shallow root system (≤15 cm), which is highly influenced by N availability in the root zone (de Jesus et al., 2023). PGPR expands root tissue, produces hormones that delay cell senescence, and reduces ethylene, while cattle manure provides gradually released N and improves soil structure. This synergy reduces N loss, increases uptake during the vegetative phase, and directs more N to the bulbs (Tang et al., 2020). These results demonstrate the synergistic effect of PGPR and cattle manure, where higher PGPR concentrations and optimum manure doses improved both NUpE and NUtE in shallot.

Figure 3 showed that the highest NUE value was shown in the treatment (P30K30) PGPR 30 mL L^{-1} + 30 t ha^{-1} cattle manure, which was 29.20 %, which increased by 133.49% compared to (P0K0) without PGPR + without cow manure (12.40 %). NUE of the plant using composted cattle manure showed a significantly greater effect compared to the application of chemical fertilizer (Koocheki & Seyyedi, 2015).

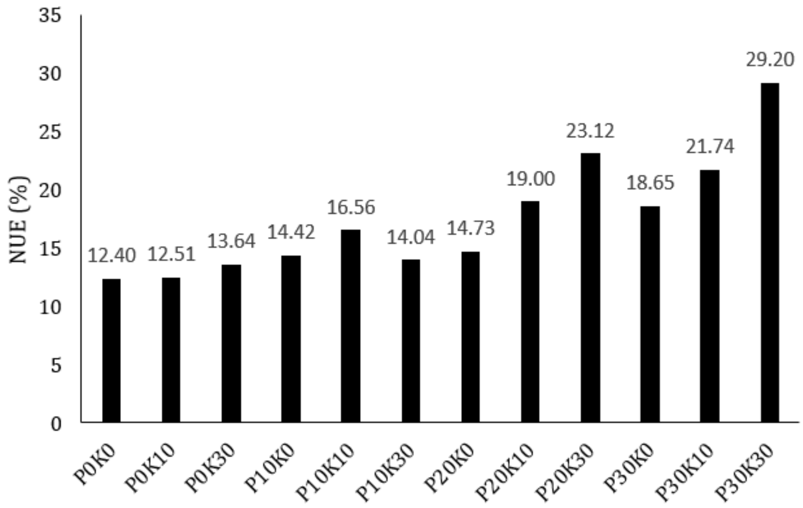

Figure 3. Nitrogen use efficiency (NUE) of shallot under the application of PGPR and cattle manure organic fertilizer

The improvement of NUE by PGPR is mediated through ACC-deaminase activity that alleviates ethylene stress, enhances photosynthetic performance, and reduces nitrogen leaching, supported by cattle manure application that supplies and stabilizes organic nitrogen (Sun & Shahrajabian, 2025). Research has shown that integrated fertilization (organic + inorganic) and PGPR can improve the plant absorption ratio of nitrogen applied by 30-50% compared to single fertilization. PGPR stimulates root growth through the production of phytohormones such as indole-3-acetic acid (IAA), which increases root surface area and the plant's ability to absorb nitrogen (Tang et al., 2020). Another study on sunflower showed that the nitrogen-enriched compost and PGPR inoculant outcomes in the highest PNUE, approximately 14–15 μmol g^{-1} s^{-1} in both 2014 and 2015, compared to the chemical nitrogen fertilizer treatment, which recorded around 8 μmol g^{-1} s^{-1} (Arif et al., 2017). Through its biological activity, PGPR enhances the efficiency of nutrient utilization by breaking down complex compounds, increasing nutrient availability, and delivering nitrogen in forms accessible to plants (Qiu et al., 2022).

CONCLUSIONS

PGPR concentration and cattle manure dose interact to influence shallot growth and yield. The combined treatment of 30 ml l-1 PGPR + 30 t ha-1 cattle manure increased bulb weight by 136.6%, achieved the highest nitrogen uptake (1 kg ha-1 day-1 at 56 DAP), and produced the most excellent nitrogen efficiencies (NUpE 64.50 %, NUtE 45.27 %, NUE 29.20 %). The study showed that the addition of cattle manure and PGPR not only increases yield but also fertilizer use efficiency of shallot, hence it can contribute to the sustainability of the crop production system.

REFERENCES

Arif, M. S., Shahzad, S. M., Riaz, M., Yasmeen, T., Shahzad, T., Akhtar, M. J., Bragazza, L., & Buttler, A. (2017). Nitrogen-enriched compost application combined with plant growth-promoting rhizobacteria (PGPR) improves seed quality and nutrient use efficiency of sunflower. *Journal of Plant Nutrition and Soil Science*, *180*(4), 464–473. https://doi.org/10.1002/jpln.201600615

Atman, A., Yuniarti, Y., Tarmisi, T., Sahara, D., Kusumasari, A., Hendra, J., Idaryani, Rawung, J. B. M., Fadwiwati, A. Y., Yapanto, L. M., Indrawanto, C., Indrasti, R., & Rubiyo, R. (2021). Increasing true shallot seed bulbs weight through manure application. *Periodicals of Engineering and Natural Sciences (PEN)*, *9*(3), 374.

Bhatt, M., Kumar, V., Bhatt, C. M., Singh, A., Singh, V., & Kala, D. (2019). Long-term effect of organic and inorganic fertilizers on soil physico-chemical properties of a silty clay loam soil under rice-wheat cropping system in Tarai region of Uttarakhand. *Journal of Pharmacognosy and Phytochemistry*, *8*(1), 2113–2118.

Bhattacharyya, P. N., & Jha, D. K. (2012). Plant growth-promoting rhizobacteria (PGPR): Emergence in agriculture. *World Journal of Microbiology and Biotechnology*, *28*(4), 1327–1350. https://doi.org/10.1007/s11274-011-0979-9

Biru, F. N. (2015). Effect of spacing and nitrogen fertilizer on the yield and yield component of shallot (*Allium ascalonicum* L.). *Journal of Agronomy*, *14*(4), 220–226. https://doi.org/10.3923/ja.2015.220.226

Brar, P. S., Kaushal, R., & Bhardwaj, G. (2019). A review on beneficial effects of PGPR and noble liquid manures in enhancing soil fertility and sustainability. *International Journal of Current Microbiology and Applied Sciences*, *8*(04), 409–415. https://doi.org/10.20546/ijcmas.2019.804.045

Congreves, K. A., Otchere, O., Ferland, D., Farzadfar, S., Williams, S., & Arcand, M. M. (2021). Nitrogen use efficiency definitions of today and tomorrow. *Frontiers in Plant Science*, *12*(637108). https://doi.org/10.3389/fpls.2021.637108

de Jesus, H. I., da Silva, A. L. B. R., Cassity-Duffey, K., & Coolong, T. (2023). Estimating fertilizer nitrogen-use efficiency in transplanted short-day onion. *Nitrogen*, *4*(3), 286–295. https://doi.org/10.3390/nitrogen4030021

De Visser, C. L. (1998). Effects of split application of nitrogen on yield and nitrogen recovery of spring-sown onions and on residual nitrogen. *The Journal of Horticultural Science and Biotechnology*, *73*(3), 403–411. https://doi.org/10.1080/14620316.1998.11510992

Dincă, L. C., Grenni, P., Onet, C., & Onet, A. (2022). Fertilization and soil microbial community: a review. *Applied Sciences (Switzerland), 12*(1198), 1–20. MDPI. https://doi.org/10.3390/app12031198

Du, S., Trivedi, P., Wei, Z., Feng, J., Hu, H. W., Bi, L., Huang, Q., & Liu, Y. R. (2022). The proportion of soil-borne fungal pathogens increases with elevated organic carbon in agricultural soils. *MSystems*, *7*(2). e01337-21. https://doi.org/10.1128/msystems.01337-21

Gallart, M., Paungfoo-Lonhienne, C., Gonzalez, A., & Trueman, S. J. (2021). Nitrogen source influences the effect of plant growth-promoting rhizobacteria (PGPR) on *Macadamia integrifolia*. *Agronomy*, *11*(6), 1064. https://doi.org/10.3390/agronomy11061064

Gebretsadik, K., & Dechassa, N. (2018). Response of onion (*Allium cepa* L.) to nitrogen fertilizer rates and spacing under rain fed condition at Tahtay Koraro, Ethiopia. *Scientific Reports*, *8*(9495), 1–8. https://doi.org/10.1038/s41598-018-27762-x

Geisseler, D., Ortiz, R. S., & Diaz, J. (2022). Nitrogen nutrition and fertilization of onions (*Allium cepa* L.): A literature review. *Scientia Horticulturae*, *291*(110591), 1–11. https://doi.org/10.1016/j.scienta.2021.110591

Gong, X., Li, J., Ma, H., Chen, G., Dang, K., Yang, P., Wang, M., & Feng, B. (2020). Nitrogen deficiency induced a decrease in grain yield related to photosynthetic characteristics, carbon–nitrogen balance and nitrogen use efficiency in proso millet (*Panicum miliaceum* L.). *Archives of Agronomy and Soil Science*, *66*(3), 398–413. https://doi.org/10.1080/03650340.2019.1619077

Gul, H., Khan, A. Z., Khalil, S. K., Rehman, H. U. R., Anwar, S., Saeed, B., Farhatullah, & Akbar, H. (2013). Crop growth analysis and seed development profile of wheat cultivars in relation to sowing dates and nitrogen fertilization. *Pakistan Journal of Botany*, *45*(3), 951–960.

Gunes, A., Karagoz, K., Turan, M., Kotan, R., Yildirim, E., Cakmakci, R., & Sahin, F. (2015). Fertilizer efficiency of some plant growth-promoting rhizobacteria for plant growth. *Research Journal of Soil Biology*, *7*(2), 28–45. https://doi.org/10.3923/rjsb.2015.28.45

Koocheki, A., & Seyyedi, S. M. (2015). Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus* L.) as affected by mother corm size and fertilization. *Industrial Crops and Products*, *71*, 128–137. https://doi.org/10.1016/j.indcrop.2015.03.085

Kurniawan, A., Karyawati, A., Rahayu, A., & Maghfoer, M. (2025). Enhancing shallot (*Allium cepa* L.) resilience to salt stress levels through the application of plant growth-promoting rhizobacteria and goat manure. *Tropical Journal of Natural Product Research*, *9*(4), 1506. https://doi.org/10.26538/tjnpr/v9i4.19

Lazcano, C., Gómez-Brandón, M., Revilla, P., & Domínguez, J. (2013). Short-term effects of organic and inorganic fertilizers on soil microbial community structure and function. *Biology and Fertility of Soils*, *49*(6), 723–733. https://doi.org/10.1007/s00374-012-0761-7

Lukman, L., & Sopha, G. A. (2014). Nitrogen effect on production, nutrients uptake, and nitrogen-use efficiency of shallot (*Allium cepa* var aggregatum). *Advances in Agriculture & Botanics- International Journal of the Bioflux Society*, *6*(2), 128–133. http://www.aab.bioflux.com.ro

Marpaung, C. A., & Maghfoer, M. D. (2023). Growth and yield response of shallots (*Allium ascalonicum* L.) on various combinations of nitrogen sources and plant growth-promoting rhizobacteria (PGPR). *Produksi Tanaman*, *011*(12), 940–951. https://doi.org/10.21776/ub.protan.2023.011.12.08

Mohammadi, K., Heidari, G., Javaheri, M., Rokhzadi, A., Nezhad, M. T. K., Sohrabi, Y., & Talebi, R. (2013). Fertilization affects the agronomic traits of high oleic sunflower hybrid in different tillage systems. *Industrial Crops and Products*, *44*, 446–451. https://doi.org/10.1016/j.indcrop.2012.09.028

Ng. Lende, A., Lehar, L., & Sine, H. M. (2020). Application of organic fertilizer and *Pseudomonas fluorescens* on the growth and yield of shallot cultivar Sabu Raijua (*Allium ascalonicum* L .) in dry land. *GSC Advanced Research and Reviews*, *5*(2), 123–130. https://doi.org/10.30574/gscarr.2020.5.2.0105

Paungfoo-Lonhienne, C., Redding, M., Pratt, C., & Wang, W. (2019). Plant growth promoting rhizobacteria increase the efficiency of fertilisers while reducing nitrogen loss. *Journal of Environmental Management*, *233*, 337–341. https://doi.org/10.1016/j.jenvman.2018.12.052

Purbajanti, E. D., Slamet, W., Fuskhah, E., & Rosyida. (2019). Effects of organic and inorganic fertilizers on growth, activity of nitrate reductase, and chlorophyll contents of peanuts (*Arachis hypogaea* L.). *IOP Conference Series: Earth and Environmental Science*, *250*, 012048. https://doi.org/10.1088/1755-1315/250/1/012048

Qiu, Z., Paungfoo-Lonhienne, C., Ye, J., Garcia, A. G., Petersen, I., Di Bella, L., Hobbs, R., Ibanez, M., Heenan, M., Wang, W., Reeves, S., & Schmidt, S. (2022). Biofertilizers can enhance nitrogen use efficiency of sugarcane. *Environmental Microbiology*, *24*(8), 3655–3671. https://doi.org/10.1111/1462-2920.16027

Safdar, H., Jamil, M., Hussain, A., Albalawi, B. F. A., Ditta, A., Dar, A., Aimen, A., Ahmad, H. T., Nazir, Q., & Ahmad, M. (2022). The effect of different carrier materials on the growth and yield of spinach under pot and field experimental conditions. *Sustainability*, *14*(12255), 1–15. https://doi.org/10.3390/su141912255

Simelane, M. P. Z., Soundy, P., & Maboko, M. M. (2023). Effect of calcium cyanamide as an alternative nitrogen source on growth, yield, and nitrogen use efficiency of short-day onion. *Agronomy*, *13*(11), 1–19. https://doi.org/10.3390/agronomy13112746

Soumare, A., Diedhiou, A. G., Thuita, M., Hafidi, M., Ouhdouch, Y., Gopalakrishnan, S., & Kouisni, L. (2020). Exploiting biological nitrogen fixation: a route towards a sustainable agriculture. *Plants*, *9*(8), 1011. https://doi.org/10.3390/plants9081011

Sun, W., & Shahrajabian, M. H. (2025). Biostimulant and beyond: *Bacillus* spp., the important plant growth-promoting rhizobacteria (PGPR) based biostimulant for sustainable agriculture. *Earth Systems and Environment*, *9*(2), 1465–1498. https://doi.org/10.1007/s41748-024-00552-4

Tang, A., Haruna, A. O., Majid, N. M. Ab., & Jalloh, M. B. (2020). Effects of selected functional bacteria on maize growth and nutrient use efficiency. *Microorganisms*, *8*(6), 854. https://doi.org/10.3390/microorganisms8060854

Tawakal, M. B., Tyasmoro, S. Y., & Wicaksono, K. P. (2025). Effect of organic fertilizers and plant growth-promoting rhizobacteria (PGPR) on nutrient residue and growth of rice (*Oryza sativa* L.). *International Journal of Environment, Agriculture and Biotechnology*, *10*(1), 074–079. https://doi.org/10.22161/ijeab.101.10

Triharyanto, E., Damayanti, N. D., Nyoto, S., & Muliawati, E. S. (2021). The role of vermicompost and PGPR on growth and formation of bulbils shallot (*Allium cepa* L. Aggregatum). *IOP Conference Series: Earth and Environmental Science*, *824*(1), 012061. https://doi.org/10.1088/1755-1315/824/1/012061

Tuhuteru, S., Sulistyaningsih, E., & Wibowo, A. (2019). The application of plant growth promoting rhizobacteria to improve shallot productivity on sandy coastal land. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 47*(1), 53-60. https://doi.org/10.24831/jai.v47i1.22271

Zhang, S., Sun, L., Wang, Y., Fan, K., Xu, Q., Li, Y., Ma, Q., Wang, J., Ren, W., & Ding, Z. (2020). Cow manure application effectively regulates the soil bacterial community in tea plantation. *BMC Microbiology*, *20*(1), 190. https://doi.org/10.1186/s12866-020-01871-y

Zhao, C., Hu, J., Li, Q., Fang, Y., Liu, D., Liu, Z., & Zhong, R. (2022). Transfer of nitrogen and phosphorus from cattle manure to soil and oats under simulative cattle manure deposition. *Frontiers in Microbiology*, *13*(916610). https://doi.org/10.3389/fmicb.2022.916610