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Research Article

Fertilizer efficiency of ammonium (NH_4^+) and nitrate (NO_3^-) by fertigation in shallot production

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ABSTRACT

Agronomic practices in Indonesia mostly still use ammonium as the primary source of nitrogen (N), whereas ammonium concentrations at certain levels can cause plant toxicity. The selection of the suitable N form (NH_4^+ and NO_3^-), especially by the fertigation method, is expected to increase the efficiency of N fertilization. This research aimed to obtain the appropriate source of NH_4^+ and NO_3^- to increase production and efficiency of fertilization in shallots. The experiment used a non-factorial randomized complete block design with four replications and six nitrogen treatments: without N, ammonium sources (urea, ZA), nitrate source (calcium nitrate), and combination of ammonium and nitrate (NPK Mutiara 16-16-16, calcium ammonium nitrate). The fertilizer doses contain N in equivalent levels, i.e., 167.9 kg N ha^{-1}. The results showed that ZA increased the chlorophyll content of leaves and N content of plant tissue, while calcium nitrate increased the size and weight (fresh and dry) of bulb per plant. The highest recovery and agronomy efficiency was obtained in the ZA application, while the highest physiological efficiency and partial factor productivity were in calcium nitrate. Therefore, nitrate has the potential for shallot cultivation because it can increase production without accumulation in the bulbs.

Keywords: *Allium cepa*; drip irrigation; nitrogen fertilizer; nitrogen form; NUE

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INTRODUCTION

Shallot (*Allium cepa* L. var. *aggregatum*) production in Indonesia fluctuated and then stagnated over the past three years. According to BPS (2023), the production of shallots in 2021 reached 2 million tons but decreased by 1.51% in 2022-2023 to 1.98 million tons. This fluctuation creates uncertainty in the availability of national shallots while demand continues to increase. ADCIS (2022) revealed that the average annual shallot consumption in 2022 was 3.02 kg per capita, an increase of 3.34% compared to the previous year of 2.93 kg per capita. A sufficient supply of shallots to meet national needs must be realized to maintain price stability among the community and prevent national inflation.

Nitrogen management in plant cultivation is essential because N deficiency can interfere with plant growth, but excessive application can cause water pollution due to the accumulation of nitrate that undergoes leaching. Nitrogen plays a role in the formation of chlorophyll for photosynthesis, therefore, N sufficiency ensures optimum plant growth and development (Suminarti & Nagano, 2015).

Plants uptake N in the form of ammonium (NH_4^+) and or nitrate (NO_3^-), and some species have different preferences. In general, NO_3^- absorption occurs mainly at low pH, while NH_4^+ absorption occurs more at neutral soil pH (Syafrizal et al., 2015). Furthermore,

NO_3^- is the form that tends to be preferred by most plants because high ammonium concentrations are toxic. Vegetables, such as cabbage, showed symptoms of toxicity when all N is applied in the form of NH_4^+, namely leaf chlorosis accompanied by burnt tips and even necrosis, followed by stunted root growth (Song et al., 2022). In onions, ammonium is needed at the beginning of growth because it can increase the absorption of phosphorus, which is helpful for root development, while the addition of nitrate is required for the next growth stage (Abbès et al., 1995).

The most common N fertilizers in Indonesia are urea and ZA (ammonium sulfate), and both fertilizers provide N in the form of NH_4^+. On the other hand, NO_3^- is an expensive fertilizer with limited availability. In the manufacture, nitrate fertilizer requires nitric acid as a raw material that is produced through a more complex process. Nitric acid is produced from ammonia (NH_3) through the Ostwald process (Alhasan et al., 2024), while NH_3 is the main ingredient in making ammonium fertilizers such as urea (Dwiputro et al., 2021).

The main issue in vegetable production in Indonesia is N efficiency. In general, the efficiency of N used by plants is around 30.2-53.2%, and up to 70% N is considered loss in the soil due to excess N application, inappropriate application methods, and low plant density (Anas et al., 2020). In shallot, highly inefficient in fertilizer application is due to it has fibrous root morphology (Murni & Purnamayani, 2019), and shallow and sparse root system leading to nutrient absorption mainly concentrates at the upper soil level (Rabinowitch & Goldstein, 2020). According to Geisseler et al. (2022), soil particle also affects N efficiency, e.g., the particles less hold nitrate causing it is sensitive to leaching by excessive rainfall and irrigation, whilst they retain ammonium although it is easily oxidized to nitrate through nitrification. On the other hand, excessive nitrate content in plant tissue could harm human health (Colla et al., 2018), the allowable daily nitrate intake is 0-3.7 mg per kg body weight (Keller et al., 2020). Therefore, improving N efficiency is essential. Ranjan & Sow (2021) pointed out that N application through a fertigation method has high fertilizer use efficiency because the fertilizer is available at the root zone, thereby minimizing nutrient loss, increasing crop productivity and yield, and reducing environmental pollution.

This research aimed to obtain the appropriate source of NH_4^+ and NO_3^- to increase production and efficiency of fertilization in shallots from various commercial N fertilizers in Indonesia. The results of this study are expected to increase the efficiency of N fertilization so that there is an increase in plant productivity and a reduction in the risk of pollution or accumulation of nitrate in plant tissues that are harmful to health.

MATERIALS AND METHODS

The research was conducted from Dec 2023 to Feb 2024 at the Cikarawang Teaching Farm (250 m above sea level), Bogor, Indonesia. Soil and plant analysis were conducted at the Laboratory of the Department of Agronomy and Horticulture, IPB University. The fertigation machine implemented the FERADS platform. FERADS calculated fertilizer recommendations based on soil nutrient analysis, plant species, and land area (Pratiwi et al., 2022).

The experiment was prepared using a non-factorial randomized complete block design with six nitrogen fertilizer treatments, namely: control (without N), urea (365 kg ha^{-1}), ZA (799.52 kg ha^{-1}), calcium nitrate (1083.23 kg ha^{-1}), NPK Mutiara 16-16-16 (1049.38 kg ha^{-1}), and calcium ammonium nitrate [CAN] (621.85 kg ha^{-1}). All of these fertilizers contain N in equivalent doses, i.e., 167.9 kg N ha^{-1}. Urea and ZA are sources of NH_4^+, while calcium nitrate is a source of NO_3^-. NPK Mutiara 16-16-16 contains 9.5% NH_4^+ and 6.5% NO_3^--, while CAN contains balanced NH_4^+ and NO_3^-, which is 13.5%. The calcium nitrate fertilizer came from PT. Meroke Tetap Jaya, while the CAN fertilizer from CV. Sadewa Agri Jaya. Each treatment was repeated four times so that there were 24 experimental plots. The plot size was a raised bed of 1.5 m x 5 m (7.5 m^2 had 177 populations), 90 cm wide, and 15 cm high, with a distance between beds was 60 cm.

Soil analysis was carried out before the experiment to determine fertilization recommendations. Soil samples were taken diagonally at 24 points and then analyzed in the laboratory using the soil nutrient extraction method (Mechlich 1). The soil had pH 6.05, C-organic of 1.97%, available of P 23.41 ppm, and available of K 226.6 ppm. Based on soil analysis FERADS recommended 311 kg SP-36 ha^{-1}, organic matter 18.3 tons ha^{-1}, 0 kg dolomite, and 0 kg potassium. The FERADS platform assumed the N level in the soil was minimum, and soil C-organic was set at 2.5%.

Shallots were planted in six rows (zigzag) with 15 cm x 20 cm spacing. The planting material used is the Bima Brebes variety. All SP-36 (100% of the recommended dose) was applied before planting, while N fertilizer was added 40% before planting (pre-plant) and 60% was applied gradually through fertigation (Table 1). Pre-plant fertilizer was given one week before planting by spreading it on the soil's surface, then the bed was covered using polyethylene mulch. Further fertilizer was applied six times, once a week, through fertigation with the same dose. Two lines of drip tape with a distance between emitters of 20 cm were placed in the bed. Automatic watering was set at a flow rate of 11.1 mL min^{-1} for each emitter. The daily irrigation volume referred to Best Management Practices (Susila, 2023), adjusted to the local potential evapotranspiration (ETo) value.

Table 1. Shalot fertilization per plot based on FERADS recommendation (7.5 m^2).

Application	N fertilizer	SP-36	KCl	Organic matter	Dolomite
Pre-planting	40% treatment	0.23 kg (100%)	0 kg (40%)	13.73 kg (100%)	0 kg (100%)
Fertigation	60% treatment	0 kg	0 kg (60%)	0 kg	0 kg
Total	100% treatment	0.23 kg (100%)	0 kg (100%)	13.73 kg (100%)	0 kg (100%)

The observed variables consisted of growth parameters (plant height, number of leaves, number of tillers, and neck diameter), production parameters (number of bulbs, bulb diameter, productivity, fresh and dry weight of bulbs per plant), and physiological parameters (tissue N analysis, leaf chlorophyll content, and bulb nitrate content). Productivity was calculated using the following formula:

$$Productivity = \frac{10{,}000}{plot\ area\ (m^2)}\ x\ \frac{population}{number\ of\ living\ plants}\ x\ yields$$

Leaf chlorophyll content was measured according to the method of Sims and Gamon (2002). Grading was also carried out on dried shallots to separate the harvested bulbs based on size. Growth and production parameters were observed on ten randomly selected plant samples for each plot, while nitrate content measurements were carried out on five random dry bulbs using HORIBA nitrate ion meter. The samples for measuring chlorophyll content were three fresh leaves composited from three different plants per plot, while for tissue N analysis, two plant samples (composite) were used that had been dried for three days at a temperature of 60 °C.

The Nutrient Use Efficiency (NUE) included recovery efficiency (RE_N), physiological efficiency (PE_N), agronomy efficiency (AE_N), and partial factor productivity (PFP_N) using the following formula (Ginting et al., 2018; Dobermann, 2005):

$$RE_N = \frac{nutrient\ uptake\ of\ N\ treatment\ - nutrient\ uptake\ of\ control}{the\ quantity\ of\ N\ applied}\ x\ 100\%$$

$$PE_N = \frac{total\ dry\ weight\ of\ N\ treatment - total\ dry\ weight\ of\ control}{nutrient\ uptake\ of\ N\ treatment - nutrient\ uptake\ of\ control}$$

$$AE_N = \frac{total\ dry\ weight\ of\ N\ treatment - total\ dry\ weight\ of\ control}{the\ quantity\ of\ N\ applied}$$

$$PFP_N = \frac{crop\ yield\ with\ N\ applied}{the\ quantity\ of\ N\ applied}$$

The data were analyzed using the F test (ANOVA) at the 5% level. If there were significant differences, analysis was continued using the Duncan Multiple Range Test (DMRT). Statistical analyses used DSAASTAT ver. 1.514.

RESULTS AND DISCUSSION

Plant growth

The results showed that the N form did not affect the vegetative growth of shallot (Table 2). This result is similar to Suddin et al. (2021) that the combination of ammonium and nitrate at specific doses, or each form of N individually, did not significantly affect the height and number of tillers of the shallot Tajuk variety at the ages of 15 and 45 days after planting (DAP). There was no significant difference between the N treatment and the control, possibly due to the organic matter mineralization process. Mineralized N in organic matter during the growing season of onions is recognized as one of the nitrogen sources for plants in unfertilized soils (Geisseler et al., 2022). Nitrogen mineralization from organic matter provided during pre-plant is suspected to supply sufficient N for plant growth in the control treatment. Grubinger (2005) stated that a reasonable estimate is that 1% of soil organic matter can provide 20-30 pounds of N per acre, or equivalent to 22.4-33.6 kg N ha^{-1}, when the soil is well-managed. These results may vary depending on environmental conditions.

Based on this research, shallots are predicted to be able to utilize N in the form of NH_4^+ or NO_3^- to support their growth. Cardoso et al. (2021) stated that the supply of N in the form of NH_4^+ or NO_3^-, which can increase the growth of mahogany seedlings, shows the flexibility of this plant in absorbing various forms of N.

Table 2. Effect of nitrogen sources on the growth of shallots.

Fertilizers	Plant height (cm)			Number of leaves			Number of tillers		
	2 WAP	4 WAP	6 WAP	2 WAP	4 WAP	6 WAP	2 WAP	4 WAP	6 WAP
Without N	23.96	36.88	40.24	15.3	30.7	33.7	4.9	7.1	8.3
Urea	26.69	40.39	45.21	16.1	32.0	36.6	5.0	7.3	8.4
ZA	25.36	37.60	41.76	14.9	29.8	34.8	4.6	6.7	8.0
Calcium nitrate	25.39	39.17	45.13	14.9	30.8	41.3	4.7	6.8	7.9
NPK	25.22	38.63	42.76	15.9	32.0	37.4	4.9	7.5	8.7
CAN	25.90	38.37	42.54	15.9	33.1	38.2	5.2	7.3	9.1
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV(%)	4.39	4.73	5.88	10.7	12.8	13.2	10.2	12.0	13.9

Note: WAP = weeks after planting, CAN = calcium ammonium nitrate, ns = not significant, CV = coefficient of variations.

Nitrogen source treatment had a very significant effect on the neck diameter of shallots (Table 3). The highest was with the application of calcium nitrate five weeks after planting (WAP), although it was not significantly different from ZA, NPK, and CAN. These results are consistent with the research of Gamiely et al. (1991) that nitrate in the nutrient solution can increase the neck diameter of shallots compared to ammonium as a single N source. In general, a large neck diameter produces large bulbs because the neck (pseudo stem) of shallots is composed of leaf sheaths, whereas the bulbs are pseudo stems underground that change shape and function to form bulbs (Kristina et al., 2023). $Ca(NO_3)_2$ provides not only NO_3^- ions but also Ca^{2+}. This element may be involved in the cell growth that helps enlarge the shallot bulb. According to Vanneste and Friml (2013), Ca^{2+} acts as a second messenger in various essential processes such as cell division, cell growth/shrinkage, and others. Calcium is also involved in nitrate metabolism, which can enhance the utilization of NO_3^- by plants (Xing et al., 2021). Shaban et al. (2019) reported that Ca can increase the yield components in garlic, possibly because this element acts as a major cofactor in many plant metabolic reactions.

Table 3. Effect of nitrogen source on shallot neck diameter (5 WAP).

Fertilizers	Neck diameter (mm)
Without N	4.29c
Urea	5.27bc
ZA	5.68ab
Calcium nitrate	6.35a
NPK	6.12ab
CAN	5.49ab
F-test	**
CV(%)	10.56

Note: CAN = calcium ammonium nitrate. Values followed by the same letter in the same column are not significantly different in the 5% DMRT test. ** = significant at α=1%, CV = coefficient of variations.

Plant production

Nitrogen sources did not significantly affect the number of shallot bulbs (Table 4). According to Gamiely et al., (1991) and Safitri et al., (2017), shallots tend to utilize N in the form of ammonium or nitrate, especially during the formation of tillers that will later produce bulbs. In ornamental plants such as Hippeastrum, the form of N does not affect the number of bulbs, but it does affect the weight and diameter of the bulbs (Vazquez et al., 2015). However, supplying nitrate solely or in combination with ammonium to shallot Tajuk variety at specific doses resulted in more bulbs than ammonium solely (Suddin et al., 2021).

The N source treatment significantly affected the bulb diameter, fresh bulb weight, and dry bulb weight per plant (Table 4). These results are in line with the research of Suddin et al. (2021) that shallots fertilized with nitrate produced greater bulbs fresh and dry weight as compared to supplements of ammonium-nitrate or ammonium. In Hippeastrum, Vazquez et al. (2015) also stated that the application of NO_3^- or in combination with NH_4^+ at a specific ratio increases the bulb weight and diameter as compared to the application of NH_4^+ alone due to increasing in root density. In onions, Gamiely et al. (1991) note that the application of nitrate alone or at a specific ratio in solution culture increases the weight and diameter along with the increase in leaf area.

Table 4. The effect of nitrogen sources on shallot production.

Fertilizers	Number of bulb	Bulb diameter (mm)	Bulb fresh weight (g per plant)	Bulb dry weight (g per plant)
Without N	8.6	19.11c	50.17c	39.14c
Urea	8.8	20.68bc	63.02abc	51.64ab
ZA	8.4	21.52b	61.52abc	49.71abc
Calcium nitrate	9.4	23.27a	73.51a	59.36a
NPK	9.0	20.56bc	65.26ab	52.63ab
CAN	9.0	20.34bc	58.34bc	47.01bc
F-test	8.7	5.54	13.67	12.97
CV(%)	ns	**	*	*

Note: CAN = calcium ammonium nitrate. Values followed by the same letter in the same column are not significantly different in the 5% DMRT test. * = significant at α=5%, ** = significant at α=1%, ns = not significant, CV = coefficient of variations.

The source and form of N did not affect shallot productivity (Figure 1). It is similar to Safitri et al. (2017) that shallot productivity is not affected by the form of N or the NH_4^+:NO_3^- ratio but is influenced by plant varieties; the NH_4^+:NO_3^- ratio only affects the dry weight of roots and leaves but not the dry weight of bulbs and the total dry weight of plants. Apart from the control treatment, all plots received the same amount of N. The results of the N treatment, which were not significantly different from the control, may be due to the plant receiving adequate N from the supplement of organic matter. Zhao et al. (2024) noted that the application of manure or organic matter improves soil properties and nutrient supply.

Although calcium nitrate showed the highest estimated productivity per hectare (Figure 1), which was consistent with the bulb weight per plant, this value was not significantly different from the other treatments. This could be attributed to the occurrence of a disease during the plant growth period. The disease symptoms began to appear when the plants reached 3 WAP, characterized by yellowing and curling of the leaves. Further symptoms of the disease could lead to bulb rot or plant wilting and death (Herlina et al., 2021). Disease spread was controlled using fungicides and by removing infected plants, which helped reduce the disease population and plant productivity.

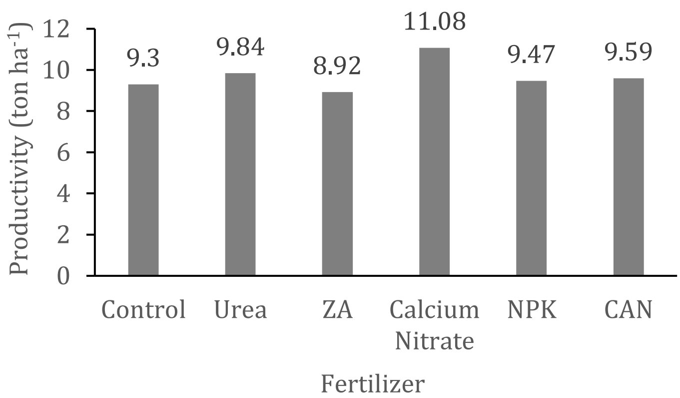

Figure 1. The effect of nitrogen sources on shallot productivity.

Although some of the nitrogen requirements of shallots may have been met through the application of organic matter, particularly in the control treatment, the form of N actually showed significantly different results between nitrate and ammonium applications, as well as in treatments without nitrogen. Calcium nitrate produced a proportion of grade A reaching 50% (from 2 kg bulbs), while without N, it produced the highest grade C bulbs (8.92%) (Figure 2). This result is consistent with the average bulb diameter in calcium nitrate fertilization, which tends to be higher than other treatments. Meanwhile, fertilizers with N sources in the form of NH_4^+ or a mixture of NH_4^+ and NO_3^- mainly produced bulbs in grade B.

Ca in calcium nitrate has a positive effect on N assimilation, especially nitrate, but has little impact on the application of ammonium. The supply of Ca with a combination of ammonium-nitrate in calcium ammonium nitrate fertilizer may not increase the proportion of grade A bulbs. Kant (2018) revealed that Ca can increase N content by activating enzymes responsible for N assimilation. Research by Xing et al. (2021) demonstrated that Ca can increase nitrate reductase activity in the leaves and roots of apple seedlings. Ca can also increase N absorption and the photosynthetic capacity of plants. Furthermore, Zhang et al. (2016) reported that Ca can increase plant growth and the activity of various enzymes involved in nitrogen metabolism in Welsh onion plants.

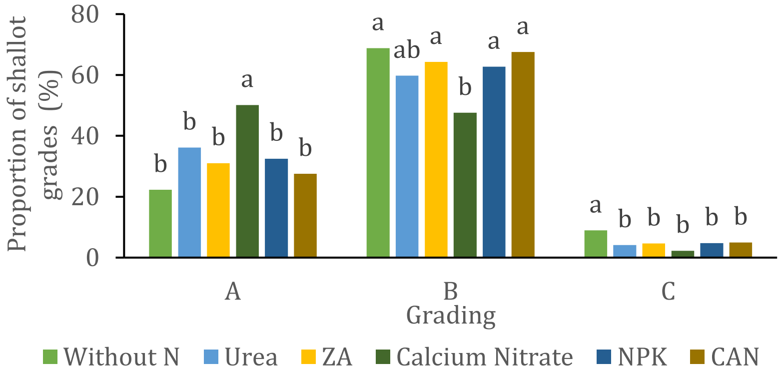

Figure 2. The effect of nitrogen sources on the proportion of shallot grades based on bulb diameter. A (≥ 25 mm), B (15 mm<α<25 mm), and C (≤ 15 mm).

Plant physiology

The N source significantly affected the chlorophyll content of shallot leaves at 5 WAP (Figure 3). ZA enhanced the chlorophyll a, b, and total of leaves, presumably due to the sulfate (SO_4^-) content in the fertilizer. According to Skudra and Ruza (2017), the increase in chlorophyll content occurs due to the addition of nitrogen and sulfur. Although not included as a chlorophyll component, sulfur is a component of succinyl Coenzyme A, which plays a role in the formation of chlorophyll (Yadav et al., 2020). Geisseler et al. (2022) stated that the effect on plant growth and yield is not always due to the form of N but can also be due to other ions contained in the fertilizer or the effect of fertilizer on the absorption of other nutrients or soil properties. Nitrogen in the form of ammonium can also increase leaf chlorophyll content. In kohlrabi, fertilization with ammonium increases chlorophyll content by 21% per leaf area compared to nitrate fertilization but does not result in greater net photosynthesis (Blanke et al., 1996).

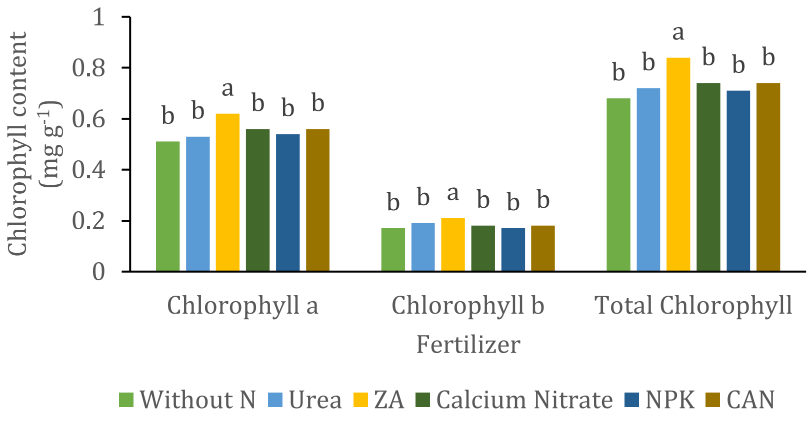

Figure 3. The effect of nitrogen sources on the content of chlorophyll a, b, and total in leaves.

The N content in plant tissues from the control treatment showed the lowest results, although it was not significantly different from the NPK treatment. Nevertheless, N uptake in this treatment is believed to be sufficient to meet the plant's growth and production needs. In natural soils, N availability is limited; however, plants can develop several adaptive responses to this condition, one of which is through the regulation of nitrogen acquisition efficiency (Kiba & Krapp, 2016). High-affinity transporters play a crucial role in efficient N uptake under low availability (Gu et al., 2013). One of the main sources of nutrients in unfertilized soils is through the mineralization of organic matter. Wang et al.

(2023) revealed that organic fertilizers can significantly increase soil carbon and nitrogen levels. The conversion of organic compounds to inorganic forms is influenced by several factors, including soil properties, temperature, chemical composition of plant residues, rainfall, and microbial composition (Grzyb et al., 2020).

ZA can increase the N content of plant tissue compared to other treatments (Table 5). High tissue N content was associated with higher leaf chlorophyll content when ZA was used. This result is consistent with Fathi (2022) that high leaf N content is associated with high chlorophyll content. Nitrogen is known to be the main component of plant chlorophyll (Fathi & Zeidali, 2021; Bassi et al., 2018). Ghannoum et al. (2005) reported that C3 plants invested 22% of their leaf N in thylakoid components such as chlorophyll, while C4 plants invested around 30%.

Table 5. The effect of nitrogen sources on %N of plant tissue and nitrate content of bulbs.

Fertilizers	N content (%)	Nitrate content of bulbs (ppm)
Without N	2.13d	514.50
Urea	2.46bc	511.50
ZA	2.66a	519.00
Calcium nitrate	2.59ab	563.00
NPK	2.32cd	533.50
CAN	2.61ab	564.50
F-test	**	ns
CV(%)	4.55	7.87

Note: CAN = calcium ammonium nitrate. Values followed by the same letter in the same column are not significantly different in the 5% DMRT test. * = significant at α=5%, ** = significant at α=1%, ns = not significant, CV = coefficient of variations.

High nitrate content in plant tissue consumed is undesirable because it can cause various health risks. The results showed that fertilization using NH_4^+ and NO_3^- had no significant difference in the nitrate content of shallot bulbs (Table 5). The nitrate absorbed by plants can immediately be assimilated and converted into a protein so that it does not accumulate much in the tissue. If nitrate absorption exceeds plant assimilation, nitrate accumulation in the tissue can occur (Colla et al., 2018). In addition, NO_3^- accumulation in shallots is likely to occur more in the leaves than in the bulbs. According to Greenwood and Hunt (1986), some of the absorbed nitrates will be transported in the xylem to various leaves in an amount that depends on the flow of water transpiration so that parts of the plant that do not transpire will have lower nitrate content. The maximum nitrate and nitrite content in vegetable plants will be achieved one week after fertilization, so harvesting the plants at this time is not recommended (Luo et al., 2022). The last fertilization in this experiment occurred when the plants were 6 WAP, and harvesting took place about two weeks later. Therefore, the nitrate content in the shallot bulbs was estimated to have decreased due to its conversion to another form.

Nitrate accumulation can vary between plant varieties within the same species (Wojciechowska & Kołton, 2014). The nitrate content of the Bima Brebes shallot bulbs in this study ranged from 511.5-564.5 ppm. According to the LAQUA HORIBA website (2016), the nitrate results in onion roots during the bulb enlargement period ranged from 850-1700 ppm, while Colla et al. (2018) reported from various studies that the average nitrate content in onions ranged from 14-279 mg kg fresh weight^{-1} with a maximum value reaching 638 mg kg fresh weight^{-1}. These results can vary depending on the planting time, cultivation techniques, and nitrate measurement methods. However, the results that can be stated in this study are that the nitrate fertilizer does not increase the NO_3^- content of shallot bulbs but can enhance the size and weight of the bulbs per plant.

Nitrogen use efficiency (NUE)

Nitrogen recovery efficiency (RE_N) is the ratio between the amount of nutrients absorbed by plants and the amount of nutrients provided through fertilizers (Ginting et al., 2018). ZA tends to show a higher RE_N than other fertilizers (Table 6). This means that the proportion of N successfully absorbed by plants due to applying ZA fertilizer is higher than other N fertilizers. This may be because ZA contains N in the form of NH_4^+, which is not readily mobile in the soil, so it is available to plants for extended periods. Fauziah et al. (2021) revealed that ZA contains N in the form of NH_4^+, which has a positively charged ion and tends to be absorbed by soil colloids, so it has lower mobility in the soil. The RE_N value in this study ranged from 7.07-14.91%, while onions that applied with various doses of urea had an RE_N value of around 14.17-19.62% (Limeneh et al., 2020). Dobermann (2005) stated that the RE_N value is affected by the method of N application (amount, application time, and form of N), as well as factors that determine plant N absorption (plant density, genotype, climate, and biotic/abiotic stress).

Table 6. Nitrogen use efficiency on various nitrogen sources.

Fertilizers	RE_N (%)	PE_N (g g^{-1})	AE_N (g g^{-1})	PFP_N (kg kg^{-1})
Without N	-	-	-	-
Urea	9.88	23.76	2.83	56.39
ZA	14.91	14.03	3.88	51.03
Calcium nitrate	11.64	50.99	2.92	62.75
NPK	9.14	29.09	3.15	54.41
CAN	7.07	44.19	1.21	55.40

Note: RE_N = Nitrogen Recovery Efficiency, PE_N = Nitrogen Physiological Efficiency, AE_N = Nitrogen Agronomic Efficiency, PFP_N = Nitrogen Partial Factor Productivity, CAN = calcium ammonium nitrate.

The highest physiological efficiency (PE_N) was obtained in calcium nitrate fertilization, followed by calcium ammonium nitrate (CAN) containing a combination of NH_4^+ and NO_3^- in equivalent amounts, namely 13.5% (Table 6). Fertilization using ammonium tends to reduce the PE_N value in shallots. Physiological efficiency is the yield obtained per unit of nutrient absorbed by the plants (Ginting et al., 2018). According to Dobermann (2005), PE_N represents the ability of plants to convert N obtained from fertilizer into plant yields. Low PE_N indicates that plants do not utilize the absorbed N to produce maximum yields (Limeneh et al., 2020). In this case, N absorption in the form of nitrate is estimated to be more efficient in increasing the dry weight of shallots compared to ammonium.

Agronomic efficiency (AE_N) is the increase in the dry weight of plants per unit of nutrient supplied through fertilizer (Ginting et al., 2018). The results showed that ZA could increase the dry weight of plants (Table 6), although shallots tended to utilize NO_3^- better than NH_4^+ based on their physiological efficiency values. On the other hand, the application of calcium ammonium nitrate was considered less efficient in increasing the dry weight of plants. However, the amount of N that was successfully absorbed from this fertilizer could be utilized well by plants to produce their dry matter.

The highest partial factor productivity (PFP_N) resulted in calcium nitrate fertilization (Table 6). The PFP_N value was obtained by comparing the amount of plant production (dry weight of bulbs) per unit of nutrient applied (Dobermann, 2005). In this study, the dose of N was the same for all fertilizers (167.9 kg N ha^{-1}), so the PFP_N value depends entirely on plant production. The greater the dry weight of shallot bulbs produced, the greater the PFP_N value.

CONCLUSIONS

Shallots could utilize N in the form of NH_4^+ or NO_3^-. The form and source of N did not affect plant height, number of leaves, number of bulbs, productivity, and nitrate content of shallot bulbs. ZA increased leaf chlorophyll content and %N of plant tissue, while calcium nitrate increased bulb size and weight (fresh and dry) per plant. In addition, ZA fertilization of shallots produced higher nutrient absorption efficiency (RE_N) and agronomic efficiency (AE_N) but had low physiological efficiency (PE_N). Meanwhile, calcium nitrate fertilization produced the highest PE_N and partial efficiency (PFP_N) values compared to other treatments. The results of this study indicate that the use of N fertilizer in the form of NO_3^- can be recommended because it increases the productivity and quality of bulbs without increasing the harmful NO_3^- content in the bulbs consumed.

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