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Reduction of Inorganic N Fertilizer with Slow Release Fertilizer Based on Activated Bentonite in Shallot Cultivation in Coastal Area

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Abstract

Coastal saline soils present significant challenges for crop production due to their high porosity, so urea fertilizers must be given in high doses. This study aims to reduce the use of inorganic nitrogen (N) fertilizers in shallot cultivation in coastal saline land with slow-release fertilizers with activated bentonite matrix. The design used was a Completely Randomized Design (CRD) with a combination of urea (U) and slow-release fertilizers (SRF) with a dose of 195.5 kg ha-1 N in different proportions, namely: (100% recommended Urea), (80% U + 20% SRF), (60% U + 40% SRF), (40% U + 60% SRF), (20% U + 80% SRF) and (100% SRF). The results showed that shallots planted with SRF showed growth performance (plant height, number of leaves, leaf greenness, fresh root weight and dry root weight) and yield (number of tillers, bulb weight per clump, dry bulb weight per clump, weight per bulb, number of bulbs per clump and bulb diameter) equal to those planted with recommended dose of urea fertilizer. Plant height and number of leaves at 6 MST had average values according to the variety description, i.e. 25-44 cm for plant height and 14-50 for number of leaves. Furthermore, slow release fertilizer (SRF) with activated bentonite matrix in this study can be used to reduce the dose of Urea given by up to 100%.

Keywords: soil ameliorant; activated bentonite; coastal soil management; Allium

Introduction

Shallots (*Allium cepa* L. *var. aggregatum*) is an important horticultural plant in Indonesia due to its unexchangeable spice function in Indonesian cookings (Ministry of Agriculture, 2023). Production of shallot in 2023 was 1,985,223 ton, exceeding domestic consumption. Asian countries such as Thailand, Singapore, Malaysia, and Taiwan are the targeting export for shallot (Ministry of Agriculture, 2024). Thus, we need to increase production both through intensification and extensification.

Central of shallot production in Indonesia is in Cental Java, especially Brebes area, which is located in coastal areas. Coastal sandy soil is suboptimal land that has the potential for expanding the area of shallots. This plant grows well in light-textured soil such as sand because of its shallow root system (Amare, 2020). In Indonesia, the area of tidal and coastal plains reaches 12.020 million ha or 6.20% of the total land (Karolinoerita and Annisa, 2020). This area spreads almost throughout Indonesia including the province of Bengkulu which has a coastline of 525 km.

Sandy coastal land has distinctive characteristics including low soil fertility, low water retention, and moderate to high soil salinity. Low water retention coupled with high rainfall (which usually occurs in Bengkulu) can result in high nitrogen losses from conventional fertilizers given through leaching (Costa et al., 2019). The low cation exchange capacity (CEC) of this soil also accelerates N leaching after fertilizer application. According to Shi et al., (2020), it is estimated that around 70% of urea is lost to the environment by seeping out of agricultural land through surface runoff and evaporation. This loss of N due to leaching results in most of the nutrients from the fertilizer given not being optimally absorbed by plants (Xu et al., 2020). and only 30% can be utilized by plants (Houlton et al., 2019).

The loss of fertilizer that is not absorbed by plants can have a negative impact on the environment. As a result of this high level of N loss, the conventional N fertilizer given is much higher than the recommended dose in an effort to ensure high yields. A recent study conducted by Rense and Maemunah (2022) reported that shallots require at least a dose of urea fertilizer (425 kg ha^{-1}), SP-36 (175 kg ha^{-1}), and NPK (325 kg ha^{-1}) in order to produce the best growth and yields. In order to reduce the loss of N nutrients from the fertilizer given, the use of slow-release fertilizer (SRF) can be one solution. With this fertilizer, it is expected that the supply of N nutrients to plants will take place in a controlled manner according to plant needs (Ye et al., 2020).

In addition to the high loss of N, sandy coastal land has another serious problem, namely low water retention capacity so that plants experience water stress (Wang et al., 2019). In this context, the SRF used must not only have slow-release capabilities but must also have a high water retention capacity. Bentonite, which is a natural clay mineral that consists mostly of montmorillonite, can be used as a material to make SRF that has both of these characteristics (Hermida and Agustian, 2019). These two characteristics of SRF can be met by bentonite because bentonite has a high water holding capacity and CEC (Paradelo et al., 2019). With high CEC, ammonium (NH_4^+) and nitrate (NO_3^-) resulting from urea hydrolysis are tightly bound in the pores and then released in a controlled manner according to plant needs (Soltys et al., 2020). In addition, with high CEC, bentonite can reduce salinity levels in sandy saline soils (Merino et al., 2021). This study aims to reduce the use of inorganic nitrogen (N) fertilizer in shallot cultivation in coastal saline media with slow-release fertilizer with activated bentonite matrix.

Research Method

Time, place, and research desain

The research was conducted in October 2023 - January 2024 a plastic house in Bengkulu City with an altitude of 10 meters above sea level. Plants were grown in polybags, experiment was arranged in a Completely Randomized Design (CRD) single factor. The treatment was combination of urea and slow-release fertilizer (SRF) at a base dose of 195.5 kg ha^{-1} N. The treatments applied included B1: 100% recommended Urea; B2: 80% Urea + 20% SRF; B3: 60% Urea + 40% SRF; B4: 40% Urea + 60% SRF; B5: 20% Urea + 80% SRF; and B6: 100% SRF. Each treatment was repeated five times, each repetition consisting of two plant polybags with a polybag volume unit weighing 5 kg. The final SRF the was analyzed for N content. The activated bentonite showed an N content of 27.7%.

Preparation of activated-bentonite slow release fertilizer.

Slow release fertilizer was made using Bentonite as matrix. The procedure followed the method of modified hydrothermal batch impregnation (Catli et al., 2020). The source of nitrogen in this study was urea. Bentonite and urea was dissolved in pure water according to Catli et al., (2020), stirred on a hot plate for 45 minutes. The mixture then was activated in furnace at temperature of 300˚C for 1 hour, resulting in solid material. The final step was to blend the solid stage into a powder fertilizer.

Planting media and transplanting plant materials

The planting media used was coastal sandy soil taken from the Lempuing area, Bengkulu City. The sand was sieved to remove litter, then it was mixed with cow dung compost using a ratio of (4:1 v/v). The planting media was then put into a 30cm x 35cm polybag. The polybags were arranged in plastic house with a distance between polybags 40cm x 25cm.

The shallot used in this experiment was shallot bulbs var. Bima Brebes. The shallot bulbs were incubated in seedling tray for 7 days until sprouting. To stimulate the uniform shoot growth, the bulbs were top-cut Sufyati and Fajri, 2010). The seven day old seedlings were then transplanted into final growing polybags to be observed.

Application of Urea and SRF Fertilizers

Slow release fertilizer was put into the plants one day after transplanting with the appropriate dose for each treatment. Meanwhile, urea fertilizer was given twice, half the dose was given one day after planting and the rest was given 2 weeks after planting. The other basic fertilizers, which were TSP and KCl, were applied the day after transplanting.

Harvesting was carried out at the age of 65 days after planting (DAP) when the shallots were approaching the criteria for harvesting with the following characteristics: slightly yellowing plant leaves, limp/deflated plant leaf bases (>60%), and red bulbs have appeared on the surface of the soil.

Data collection.

Observation and data collection were taken to measure the components of plant growth (plant height (cm), number of leaves per cluster, number of shoots per cluster, fresh root weight (g), dry root weight (g), and leaf greenness level), and the components of plant yield (number of bulbs per cluster, bulb diameter (cm), fresh weight of bulbs per cluster (g), dry weight of bulbs per cluster (g), and weight per bulb (g).

Data analysis.

The data obtained were then analyzed statistically using Analysis of Variance (ANOVA) using the F test at a level of 5%. The significant effects from the ANOVA calculation then were continued to be analyzed using Least Significant Different Test at 5%. Non-significant data from Anova were presented and analyzed descriptively.

Results and Discussion

The results of the ANOVA showed that the combination treatment of Urea and SRF fertilizers had no significant effect on plant growth (plant height, number of leaves, greenness of leaves, fresh weight of roots and dry weight of plant roots) measured at harvest compared to the standard dose of urea (Table 1). This means that SRF or its combination with urea had similar effect on shallot growth and yield.

Table 1. F-values of growth and yield variables of shallot

Variables	F – values	CV (%)
Plant height	1.41 ns	10.54
Number of leaves	0.91 ns	25.64
Leaf greeness	0.95 ns	6.66
Number of tillers	1.01 ns	30.94
Root dry weight	1.60 ns	28.52
Root fresh weight	1.89 ns	16.96
Weight of bulb per cluster	1.24 ns	37.38
Air-dried of bulb per cluster	1.37 ns	42.33
Weight per bulb	0.60 ns	37.43
Number of bulb per cluster	1.13 ns	17.05
Diameter of bulb	1.12 ns	19.21

Notes: (ns) non significant, (CV) Coefficient of Variance.

The mean comparison among the treatments showed that the average plant height for B2 (35.65 cm), B3 (39.32 cm), B4 (36.32 cm), B5 (37.91 cm) and B6 (35.85 cm) was slightly higher compared to B1 (33.21 cm) (Table 2). For the number of leaves than the control, while B2 and B6 showed a lower value (2.9 strands). The values of leaf greenness were ranged between 55.35 and 59.7. The same pattern was also found in the root weight. Referring to the description of shallot var. Bima Brebes, it was turned out that the plant height of the variety was 34.5 cm (25cm – 44cm), the number of tillers was 7- 12. The plant growth in this study were normal in the height but the growth of tillers was sufficiently supported from the treatments B3 and B4. Based on the adoption study of the Bima Brebes shallot variety in Brebes Regency conducted by Sinung et al., (2018), Brebes shallots produced an average of 4 to 9 tillers per cluster.

Table 2. The average of plant height, number of leaves, number of tillers, leaf greenness, root weight of shallot

Treatments	Plant height (cm)	Number of leaves	Number of tillers	Leaf greenness	Root weight (g)
B1 (100% Urea)	33.21	19.7	6.4	57.06	0.64
B2 (80%U+20%SRF)	35.65	19.6	6.4	58.51	0.73
B3 (60%U+40%SRF)	39.32	23.5	7.1	59.71	0.88
B4 (40%U+60%SRF)	36.32	21.3	6.9	59.31	0.76
B5 (20%U+80%SRF)	37.91	20.3	6.3	56.73	0.61
B6 (100%SRF)	35.85	16.8	5.7	55,35	0.60

The absence of a significant difference between the combination treatments of SRF and urea in various proportions (B2, B3, B4, and B5) with the treatment of 100% urea occurred because the release pattern of nutrients from slow-release fertilizers was in line with the nutrient absorption needs of shallot plants, thus ensuring adequate growth. The release of SRF nutrients using active bentonite may be similar to standard urea, resulting in comparable growth. Previous research conducted by Liu et al., (2020) showed that the efficiency of nutrient absorption in plants depend on the pattern of release of fertilizer.

Table 3. The average of fresh weight of bulb, air-dried weight of bulb, number of bulb, weight per bulb, and diameter of bulb

Treatments	Fresh weight of bulb per cluster (g)	Air-dried weight of bulb per cluster (g)	Number of bulb per cluster	Weight per bulb (g)	Diameter of bulb (mm)
B1 (100% Urea)	33.21	19.7	7.0	57.06	0.64
B2 (80%U+20%SRF)	35.65	19.6	7.1	58.51	0.73
B3 (60%U+40%SRF)	39.32	23.5	8.2	59.71	0.88
B4 (40%U+60%SRF)	36.32	21.3	7.4	59.31	0.76
B5 (20%U+80%SRF)	37.91	20.3	7.1	56.73	0.61
B6 (100%SRF)	35.85	16.8	6.7	55,35	0.60

This study showed that the combination treatment of Urea and SRF fertilizers had no significant effect on the crop yield variables measured at harvest (number of tubers, tuber weight per cluster, air-dried weight of tubers per cluster, weight per tuber, and tuber diameter) compared to the standard dose of urea. The average tuber weight per cluster for treatments B2 (14.106 g), B3 (20.098 g), B4 (17.678 g) and B5 (16.832 g) was slightly higher than B1 (13.324 g) while treatment B6 showed a lower value (12.694 g). The same pattern was also found in the variables of dry weight of tubers per cluster, weight per tuber, number of tubers per cluster and tuber diameter. The results of this study are in line with the latest study by Chen et al., (2019). on the effectiveness of slow-release fertilizers which reported that slow-release fertilizers did not reduce yields but still provided environmental benefits such as reduced nitrogen runoff. The same thing was also expressed by Smith et al., (2020) that slow-release fertilizers were as effective as conventional fertilizers in encouraging the growth and yield of lettuce plants. The same case was also experienced by Rugayah et al., (2018) in their findings reporting that the use of various types of nitrogen source fertilizers given to kale plants did not show any significant differences, but the treatment of slow release urea type bentonite agronomically provides opportunities to increase plant growth and yield.

It has been mentioned that the use of slow-release fertilizer using an active Bentonite matrix at any dose did not have a significant effect on the growth and yield of shallots compared to the standard dose of urea. This shows that both fertilizers provide similar nutrient availability and absorption efficiency in the coastal saline soil conditions tested. In this study, the application of slow-release fertilizer using an active bentonite matrix produced similar yield components to the standard urea treatment. This is because the nutrient release pattern of the slow-release fertilizer is in line with the nutrient absorption needs of shallots, ensuring adequate growth and yield. The release of SRF nutrients using active bentonite may be similar to standard urea, resulting in comparable growth results. Previous research conducted by Liu et al., (2020) showed that the efficiency of nutrient absorption in plants can depend on the fertilizer release pattern. This finding means that slow-release fertilizers can be a viable alternative to conventional nitrogen fertilizers.

Coastal saline soil conditions may hinder the unique performance of the slow-release properties of SRF. Salinity conditions can affect nutrient uptake and plant growth, potentially overriding the benefits of slow-release formulations. Shallots are shallow-rooted plants that require high N (Amare, 2020). The need for high and rapid nutrients can be met from conventional urea that is given and then get enough nutrients from the provision of slow release that works more slowly.

Long-term studies can help answer whether SRF with the use of activated bentonite can provide cumulative benefits that are not seen in just one growing season. Studies should include several growth cycles to assess the long-term impact on soil health and plant growth (Lee, 2022). As stated by Wang et al., (2023) testing the impact of SRF using an activated bentonite matrix on different plants with longer growth periods or different nutrient needs may provide more significant results.

Activated bentonite is widely used in slow-release fertilizer formulations, especially in combination with urea, due to its unique properties that improve nutrient retention and release characteristics. Activated bentonite plays an important role in improving the characteristics of urea-based slow-release fertilizers. Its ability to absorb and retain urea, release urea in a controlled manner, improve soil structure, reduce volatilization, enhance microbial activity and contribute to environmental sustainability. makes it a very valuable component in modern agricultural practices. The incorporation of activated bentonite in fertilizer formulations can provide significant progress in developing efficient and environmentally friendly fertilization strategies.

Bentonite has a high surface area and cation exchange capacity (CEC), which allows it to effectively absorb and retain urea molecules. This adsorption helps reduce urea leaching, thereby ensuring long-term availability of nitrogen to plants (Rao and Ghanshyam, 2019). Intercalation of urea into the activated bentonite layer results in a controlled release of urea. This process slows down the hydrolysis of urea, resulting in a stable release over a long period of time (Huang et al., 2020). This controlled release mechanism is essential for increasing the efficiency of nitrogen utilization by plants and reducing the environmental impacts associated with urea use.

Activated bentonite improves the physical properties of soil by increasing its water retention capacity and porosity. This results in better root penetration and water availability which in turn supports optimal utilization of urea present in the fertilizer (Zaman et al., 2018).

Urea which is prone to volatilization often results in significant nitrogen loss. The presence of activated bentonite in the slow-release fertilizer matrix helps reduce this loss by absorbing ammonia and reducing its release into the atmosphere (Pan et al., 2021). This process not only conserves nitrogen but also minimizes the impact on the environment.

Activated bentonite also has a positive effect on microbial activity in the soil. The slow release of urea ensures a consistent supply of nitrogen that can support microbial growth and activity (Wang et al., 2022). The active microbial community contributes to the overall fertility and health of the soil which can further enhance plant growth. Integration of activated bentonite into slow-release fertilizers Urea-based slow-release fertilizers also contribute to reducing the environmental impact of agricultural cultivation practices. By increasing the efficiency of nutrient use and minimizing nitrogen loss through leaching and volatilization, slow-release fertilizers can lead to sustainable agriculture (Zhang et al., 2023).

Conclusion

The application of SRF using active bentonite matrix gave comparable results in terms of growth (plant height, number of leaves, leaf greenness, fresh root weight and dry root weight) and yield of shallots (number of tillers, bulb weight per clump, dry bulb weight per clump, weight per bulb, number of bulbs per clump and bulb diameter) compared to standard urea doses on coastal saline soils. Slow release fertilizer can be a viable alternative to conventional nitrogen fertilizers. Slow release fertilizer can reduce the need for urea fertilizer by 100% while maintaining the growth and yield of shallots.

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