The Effects of Zeolite-Based Slow-Release Nitrogen Fertilizer and Sulfur on the Dynamics of N,P,K, and S Soil Nutrients, Growth and Yield of Shallot (*Allium cepa* L.)

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Abstract—**Shallot or red onion is one of the horticultural commodities that has good economic value as it is needed for almost every cuisine. The aims of the research were to determine 1) the effect of nitrogen slow-release zeolite-based NZEO-SR fertilizer and elemental Sulfur on the dynamics of soil main nutrients N, P, K, and S, and their uptake the red onion plants 2) the effect of slow-release N fertilizer on the growth and yield of shallots; 4). the effect of S fertilizer on the growth and yield of red onion and 5) the interaction of slow-release N fertilizer and S soil nutrient dynamics and the growth and yield of shallots. The research was conducted in a greenhouse using Inceptisols. soil analysis was carried out in the the Land Resource Laboratory, Faculty of Agriculture, Jenderal Soedirman University, Indonesia. The design of this study was a Completely Randomized Block Design (CRBD) with two factors i.e. slow-release nitrogen fertilizer NZEO-SR and elemental sulfur. The test plant used was shallot Bauji variety. The slow release nitrogen fertilizer were applied at 0 , 100·, 200, dan 300 kg.ha^{-1}, while the rates of S fertilizer were 0, 25, 50 and 75 g.ha^{-1}. The variables observed consisted of selected soil chemical properties, available N, P, K, and S, N and S uptake, growth and yield of shallots. The results showed that the nitrogen slow release fertilizer applications increased soil available N and S, N uptake, the number of tubers, the weight of fresh shallot bulbs but decreased the soil available P. The applications of S increased soil electrical conductivity and available N and S but decreased the soil pH, available soil P, S and N uptake, and number of bulbs. The applications of S at the highest rate (75kg.ha^{-1}) decreased the bulbs fresh and dry weight. The combination of 200 kg.ha^{-1} NZEO-SR and 75 kg.ha^{-1} S gave the best results in available soil N. The applications NZEO-SR and S generated negative interaction on the soil available P.**

Keywords—slow release nitrogen fertilizer, zeolite, sulfur, shallot

I. Introduction

Red onion or shallot (*Allium cepa* L.) is a very popular and somewhat pricy vegetable in Indonesia as it is a spicy needed for almost every cuisine. It is estimated that shallot consumption has increased by 10 % for the last four years [1]. The main essential nutrients that are mostly required by shallots are N (nitrogen) and P (phosphor) for the vegetative growth and S (sulfur) for flavor and taste development.

NZEO-SR is a zeolite-based, slow-release N fertilizer made through impregnation and adsorption of urea fertilizer into zeolite nano-sized pores and negatively charged surfaces [2]. Zeolites are naturally occurring crystalline hydrated aluminosilicate minerals having three dimensional crystal structure with very high cation exchange capacity and surface area [3]. The negatively charged surface of zeolites is counterbalanced by cations of alkali or alkaline-Earth metals (such as sodium, potassium, and magnesium). Due to these characteristics, zeolites have been widely used in many industrial areas such as for cation exchanger [4][5], waste water treatments [6][7] and a reaction catalyst[8]. In the field of agriculture, zeolites have been used to reduce gaseous N losses either in water logged or non water logged soils[9][10][11], as a slow release fertilizer [12][13][14][15]. Zeolites have also been reported to improve phosphorus uptake by plants [16}.

Sulphur (S) plays a significant role in the nutrition of onion plants. However, S is rarely included in the plant fertilization resulting in low S availability in some soils. The applications of Sulphur in onion have been reported to increase the bulb production and enhanced the bulb quality particularly pungency and flavors [17][18][19].

This experiment was designed to evaluate the effects of NZEO-SR slow-release fertilizer in combination with S applications on N, P, K and S dynamics and growth and yields of red onion in an Inceptisol.

II. Materials and Method

A. Materials

The slow-released fertilizer NZEO-SR was obtained through the method described by Kharisun et al. (2017). 100-mesh ground natural zeolites were activated hydrothermally at 100°C using 2.5 N NaOH solution for 12 hours. The excess of NaOH was then removed by leaching processes. The activated zeolites were mixed with urea fertilizer, 100-mesh size montmorillonite (as an adhesive) and rice husk ash by adding water amounting to 30 % w/w. The proportions of zeolite, urea-N, montmorillonite, and rice husk ash were 10, 1, 0.5, 0.5, respectively. The mixtures were then granulated to the size of 2.0-2.5 mm.

B. Methods

The experiment was carried out in a greenhouse and laid out in the Completely Randomized Block Design (RCBD) with 2 factor i.e. NZEO-SR fertilizer and Sulphur. Each factor consisted of 4 rates with 3 replications generating 48 experimental units. The details of the treatments are depicted in Table I.

TABLE I.   EXPERIMENTAL FACTORS AND RATES

Factor	Code	Rates (kg ha^{-1})
NZEO-SR	N0 (control)	0
	N1	100
	N2	200
	N3	300
Sulphur	S0 (control)	0
	S1	25
	S2	50
	S3	75

The soil was air-dried and sieved to the granule size of 2 mm. Each polybag received an amount of oven-dry 10 kg-equivalent of soil. The fertilizers were applied once, just before planting. The variables observed included soil available N, P, K and S, plant uptake of N, P, K and S, the growth and the yield of red onion, and selected soil chemical properties. The laboratory analysis was undertaken in the Soil Science Laboratory of The Faculty of Agriculture, Jenderal Soedirman University, Indonesia.

III. RESULTS AND DISCUSSION

The analysis of variance showed that the applications of slow-release NZEO-SR and elemental Sulfur gave significant effects on most observed variables. Both factors independently affected the soil available N, P, and S, uptake of N and P, and bulb fresh weight (Table I.). The applications of Sulphur also gave significant effects on soil pH and electrical conductivity (EC). There were interactive effects between NZEO-SR and S on the soil available N and S.

TABLE II.   ANALYSIS OF VARIANCE OF TREATMENTS

No	Variable	Treatment		
		N	S	N x S
1.	Avail-N	*	*	*
2.	Avail-P	*	*	*
3.	Avail-S	*	*	
4.	Avail-K			
5.	N uptake	*	*	
6.	P uptake	*	*	
7.	S uptake		*	
8.	Bulb fresh weight	*	*	
9.	Bulb dry weight		*	
10.	Bulb diameter			
11.	Soil pH		*	
12	Soil EC		*	

Notes: *=significant at P < 0.05. Avail-N = Soil available N; Avail-P = Soil available P; Avail-S = Soil available S; Avail-K = Soil available K.

Table II. also shows that the applications of slow-release fertilizer and S did not gave significant effects on the availability of K in the soil. In NZEO-SR fertilizer, the negatively charged zeolite surfaces are saturated with NH_4^+ ions (Kharisun et al., 2017). These cations are gradually released to the soil solution in exchange of other cations already present in the soil like K^+. This mechanism explains why K availability in the soil was not affected by the application of the slow N-release fertilizer.

As can be seen from Table 2, soil available N increased with the higher rates of NZEO-SR applications particularly when S applied at the highest rate. This phenomenon could be attributed to two mechanisms. At the higher rates of NZEO-SR applications, more NH_4^+ adsorbed in the zeolite fertilizer was gradually released to the soil through the cation exchange mechanism resulting in more N being available to the plant. The second mechanism is that the applications of S markedly lowered the soil pH (Table 3). The low pH conditions might have inhibited the gaseous N loss through ammonia volatilization leading to more N available to the plants. A study reported that ammonia emissions could be reduced by 15 percent with the applications of urea and S [20]. The soil acidification process as the results of H_2SO_4 formation resulted in more favorable conditions that could inhibit the conversions of NH_4^+ to NH_3 gas [9][10].

TABLE III.   SOIL AVAILABLE N AND P AS AFFECTED BY INTERACTIONS BETWEEN SLOW-RELEASE FERTILIZER NZEO-SR AND SULFUR

Variabel	NZEO-SR	S			
		S0	S1	S2	S3
Avail-N (ppm NH_4^+)	N0	34,03B ab	29,78B b	66,44A b	68,56A b
	N1	27,54C b	29,89C b	83,41B a	108,43A a
	N2	45,57B a	51,72B a	50,92B bc	116,72A a
	N3	25,79C b	46,76B ab	45,74B c	101,23A a
Avail-P (ppm P_2O_5)	N0	11,22A a	5,20B a	4,76B a	6,33B ab
	N1	6,84A bc	0,38B b	1,92B b	4,80A b
	N2	7,76A b	6,92AB a	3,58C ab	4,30BC b
	N3	3,98B c	1,98B b	1,17B b	7,62A a

Notes: Numbers followed by same small letters in the same column and variable and numbers followed by capital letter in the same row are not significantly different according to DMRT at P < 0.05. Avail-N = Soil available N; Avail-P = Soil available P.

Table III. shows that in the control plot, where there was no S applied, the applications of NZEO-SR decreased the plant-available P in the soil. The highest reduction in the available P was observed in the application of NZEO-SR at the highest rate (300 kg. ha^{-1}). The applications of NZEO-SR increased the availability of soil N, thus more N could be taken up by the plants and made the red onion plants grow well. This condition would result in more P nutrient being taken up by the plants which in turn lead to the reductions of the plan-available P in the soil. The similar results were also observed with the applications of S in the plots received no N fertilizer (Table 2). The reductions of the available P were mainly due to the decline in the soil pH as a result of the addition of elemental S. In low pH conditions, Al becomes more active and can be toxic to the plants. This Al form is also able to react with plant-available forms of P like $H_2PO_4^-$ to produce a non-soluble substance which is not available to the plants [21].

As depicted in Table 3, the applications of elemental S markedly decreased the soil pH from a pH of 5.8 in the control to 3.64 in the application of S at 300 kg. ha⁻¹. The soil pH was negatively correlated with the rates of elemental S following a linear relationship (Figure 1). The great reductions were mainly due to the more elemental S that could undergo oxidation reactions mediated by soil microorganisms to form SO_4^{2-} ions [22]. There are various organisms capable of mediating the oxidation reactions. But most studies have been focused on sulfur-oxidizing bacteria in the family of *Thiobacilliaceae* especially in the terrestrial environments [21][23].
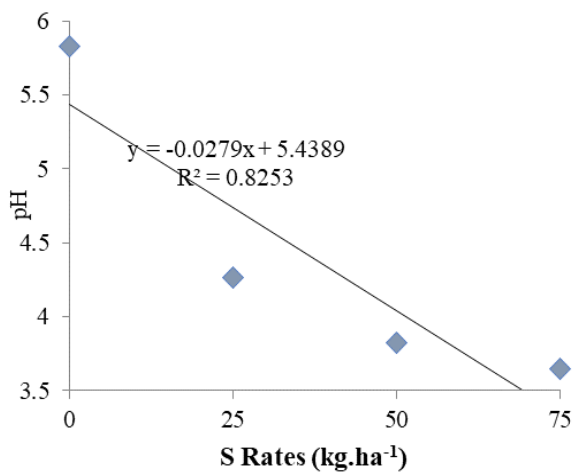

Fig. 1. Relationships between soil pH and rates of Sulfur applications

The consistent results were observed with the applications of S on the nitrogen uptake by the plants. Table 3 demonstrated that the applications of S at the rate of 75 kg.ha⁻¹ reduced the N uptake by more than 50%. This might be attributable to the aluminum toxicity and lower microbial activity responsible for the transformation of N in the soil.

TABLE IV.   SOIL AVAILABLE S AND K, S UPTAKE BY SHALLOTS AND SOME SOIL CHEMICAL PROPERTIES

Factor	N uptake (mg/clump)	Av-S (ppm S)	S uptake (mg/clump)	Soil pH	EC (µS/cm)
NzeoSR					
N0	868.9b	589.4ab	276.4a	4.44a	1549a
N1	774.0c	648.3a	271.0a	4.29a	1816a
N2	988.9a	498.4b	293.5a	4.41a	1768a
N3	684.c	538.9ab	202.8a	4.41a	1538a
Sulfur					
S0	1231.6a	27.2 d	303.5a	5.82a	320d
S1	649.9b	521.6 c	205.6b	4.26b	1397c
S2	642.8b	762.1 b	292.9a	3.82c	2137b
S3	573.6c	964.6 a	241.2b	3.64c	2817a

Notes: Numbers followed by same small letters in the same column and factor are not significantly different according to DMRT at P < 0.05. Av-S =soil available S.

The application of slow-release N fertilizer NZEO-SR was not able to increase the N uptake by the red shallots (Table 3). It was expected that more N that was gradually released from the fertilizer to the soil could be taken up by the plants [24][25]. This inconsistency might have been attributed the fact that the rates of NZEO-SR were too low. The highest rate of NZEO-SR is 300kg ha⁻¹ which is equivalent to only 30 kg urea ha⁻¹ or 13.5 kg N ha⁻¹.

As indicated by Table 3, there seems to be a contradiction between the S availability and the S uptake with the applications of elemental S. The applications of S consistently increased the plant-available S in the soil with the higher S applied. However, this increased availability of S did not improve the plant uptake of S. This might be attributed to the lower pH conditions which were not favorable for the S uptake. When the soil pH declines to 5 or less, aluminum (Al) is more soluble and may become toxic. In low pH Al^{3+} is released to the soil. This ionic form is readily taken up by the roots and causes Al toxicity as it inhibits cell elongation and blocks the mechanisms of cell division resulting in stunted roots and poor root hair development [26]. The root growth retardation also leads to other ions and water absorption by the plants [27].

The increase in SO_4^{2-} as a result of the elemental S applications was also indicated by the increase in the soil electrical conductivity (EC) (Figure 2). Electrical conductivity basically measures the concentrations of ions either cations or anions in a solution.
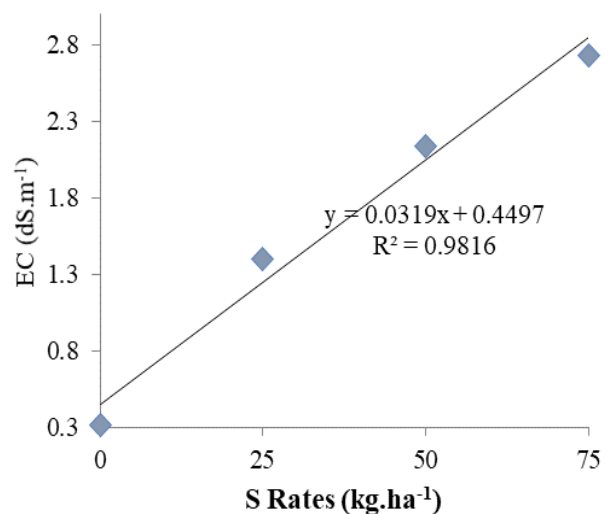

Fig. 2. Soil Electrical Conductivity (EC) at different rates of S applications

As depicted in Figure 2, the EC values were linearly correlated with the rates of S applications. This is because the applied S will undergo oxidation to form sulfate ions mediated by various sulfur-oxidizing microbes living in the soils. The application of S as low as 25 kg ha⁻¹ increased the EC value by 336% while the application of S at the highest rate (75 kg ha⁻¹) increased very sharply the EC values from 320 to 2817 µS/cm. This EC value is considered to be above the critical value of most plants. An experiment conducted

by [28] showed that during the germination stage, onion plants were tolerant to the EC values up to 9.5 mS/cm. However, the onion plants were very sensitive to the EC when the seedlings were already transplanted. The plants were adversely affected by the EC values as low as 1.2 mS/m. The onion plant sensitivity to high EC values explains why the S uptake by red onion plants in the present experiment was reduced at the highest rate of S application (Table 3). As can be seen from Table 4, the S applications up to the rate of 50 kg.ha^{-1} increased the bulb fresh weight and dry weight and thereafter the bulb weight decreased as the rate was increased to 75 kg.ha^{-1}.

TABLE V. RED ONION GROWTH AND YIELD PARAMETERS AS FFECTED BY THE APPLICATIONS OF NZEO-SR FERTILIZER AND S.

Factor	NB	BFW (g/clump)	BDW (g/clump)	ABD (cm)
NzeoSR				
N0	8,25 ab	27,35 ab	23,42 a	13,84 a
N1	8,66 ab	23,39 b	21,68 a	14,90 a
N2	7,83 b	27,85 a	24,66 a	16,45 a
N3	9,33 a	24,24 ab	21,12 a	17,15 a
Sulfur				
S0	9,41 a	28,80 a	25,29 a	16,57 a
S1	7,58 c	22,55 b	19,40 b	15,66 a
S2	9,0 ab	28,36 a	25,92 a	15,81 a
S3	8,08 bc	23,12 b	20,27 b	14,29 a

Notes: Numbers followed by same small letters in the same column and factor are not significantly different according to DMRT at P < 0.05. NB=Number of Bulbs; BFW=Bulb Fresh Weight; BDW=Bulb Dry Weight; ABD=Average Bulb Diameter.

IV. CONCLUSION

Based on the results of the experiment, some conclusions can be drawn:

1. The applications of slow-release fertilizer NZEO-SR and elemental Si affected the availability of N, P and S, growth and yield of red onions, did not affect availability of soil K.

2. The results showed that the nitrogen slow release fertilizer applications increased soil available N and S, N uptake, the number of tubers, the weight of fresh shallot bulbs but decreased the soil available P

3. The applications of S increased soil electrical conductivity and available N and S but decreased the soil pH, available soil P, S and N uptake, and number of bulbs.

4. The combination of 200 kg.ha^{-1} NZEO-SR and 75 kg.ha^{-1} S gave the best results in available soil N.

5. The applications NZEO-SR and S generated negative interaction on the soil available P.

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