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RESEARCH ARTICLE

DEVELOPMENT AND TESTING OF ZEOLITE-BASED SLOW RELEASE FERTILIZER NZEO-SR IN WATER AND SOIL MEDIA

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ABSTRACT

The research was carried out in the Laboratory of Soil Science and greenhouse Agriculture Faculty, Jenderal Soedirman University. This experiment was aimed at studying the effects of fertilizer adhesive levels and fertilizer granule size on water penetration, water, and soil chemical properties. The research was laid out according to Completely Randomized Design (CRD), consisting of 2 factors i.e. fertilizer granule size (2 sizes) and fertilizer adhesive (5 levels). There were 10 types of NZEO-SR fertilizers tested with 3 replications. The fertilizers were tested in water and soil media, totaling 60 experimental units. The results showed that NZEO-SR fertilizer having a diameter of 2.5 - 3.0 mm in combination with 3% (w/w) fertilizer adhesive had the highest ability to resist water penetration. Levels of fertilizer adhesive material gave significant effects on pH (H_2O), electrical conductivity (EC) and water-soluble N. Diameter of fertilizer had no effect on all the variables studied, except for water-soluble N. Levels of fertilizer adhesive significantly affected the pH (H_2O) and total soil N, but did not show significant effects on the EC and soil available N. The diameter of fertilizer had no effect on all soil chemical variables.

Keywords: fertilizer, NZEO-SR, zeolite

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INTRODUCTION

Nitrogen (N) chemical fertilizers currently used by the farmers commonly have N concentration with high solubility, so they are readily available for plant uptake. However, those fertilizers when applied to the soil tend to have a very poor efficiency. There are a number of mechanisms by which N is lost, among others are gaseous losses through ammonia (NH_3) volatilization and denitrification and losses through leachings processes and surface run-off (Kimura & Kurashima, 1991; Whitehead, 2000). By these mechanisms, the loss of N can be as high as 80 percent of applied N (Freney, 1997; D. X. Lin, Fan, Hu, Zhao, & Luo, 2007). These losses may lead to the environmental concerns i.e. pollution of waters and groundwater as a result of leached N and the production of greenhouse gases that contribute to the global warming problem. The use of chemical fertilizers may also result in a decrease in the quality of soil chemical and physical properties. Continuous applications of chemical N fertilizers may cause soil nutrient imbalances leading to higher plant uptake of other nutrients not

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applied to the soil. Soil physical properties are adversely affected as the soil particles are more dispersed as a result of the reduction of binding force leading to damage to soil structure and infiltration capacity. The reduction in infiltration capacity will result in more surface run-off thus it will reduce the groundwater reserve and may cause a flood incidence. The adverse effect of chemical N fertilizers can be solved through the development of more efficient slow-release fertilizers. NZEO-SR is a zeolite-based N fertilizer developed to achieve greater N use efficiency and more environmentally friendly.

NZEO-SR fertilizer is made from natural zeolite as the main material and clay mineral of 2: 1 type (montmorillonite) as the adhesive material. Most of the materials used to develop the NZEO-SR fertilizer are locally available. Zeolite mineral reserve in Indonesia is deemed a potential resource as it was spread out in more than 45 locations. Natural zeolite as the main component of NZEO-SR fertilizer is capable of reducing N losses by adsorbing NH_4^+ cations released by N fertilizer onto its exchange sites. Zeolites are aluminosilicate minerals having tridimensional crystal structures nano-sized pore channels frameworks resulting in a very high surface area. The negative charges generated in the zeolite structured are formed from the isomorphic substitution of Si^{4+} ion in the tetrahedral structure by tri-valence Al^{3+} ions (Purnomo, Lenora, Budhijanto, & Hinode, 2017; Sánchez & Pariente, 2011). These negatively charged sites are counterbalanced by positively charged ions (cations) such as Na^+, K^+, Ca^{2+} and Mg^{2+} which are exchangeable (Bobonich, 1990).

In NZEO-SR fertilizer, zeolites are loaded with NH_4^+ released from urea hydrolysis. NH_4^+ ions are adsorbed on the negatively charged sites located in the nanopore channels, thus they are not accessible to the microbes. The adsorbed ions can be released through cation exchange mechanisms. Therefore, zeolite-based fertilizer like NZEO-SR can act as a slow-release fertilizer. The controlled-release of NH_4^+ will improve N use efficiency, plant growth and reduce environmental pollution (Leggo & Ledésert, 2001; Tsintskaladze et al., 2016; Xiong-hui, Sheng-xian, Yan-hong, & Yu-lin, 2007; Yan, Jin, He, & Liang, 2008). The use of controlled released N fertilizers improves the N uptake efficiency and reduces gaseous N losses through ammonia volatilization and denitrification (Cabezas et al., 2005; de Almeida Acosta et al., 2011; De Castro Gava, Ocheuze Trivelin, Vitti, & De Oliveira, 2005; Z. Cheng Lin et al., 2012; Pinto Coelho, Demoura, & Moreira, 1997; Raun & Johnson, 1999). The slow release NH_4^+ prevents nitrification process as most of the NH_4^+ ions are taken up by plants. This will reduce NO_3^+ leachings and prevent gaseous losses through the denitrification process.

NZEO-SR fertilizer is made in the form of granules with main adhesive material montmorillonite. Granule size and adhesive concentrations will affect fertilizer resistance to water penetration that leads to affect the fertilizer solubility. This experiment was aimed at studying the effects of fertilizer adhesive levels and fertilizer granule size on water penetration, water, and soil chemical properties.

MATERIALS AND METHODS

The research was carried out in the Laboratory of Soil Science Agriculture Faculty, Jenderal Soedirman University. Fertilizer NZEO-SR materials were composed of natural zeolite, N-urea, type 2:1 clay mineral (montmorillonite) and rice husk. Preparation of materials: a). Natural zeolite was prepared by grounding to be powder and sieving to pass through a 100-mesh diameter sieve. The zeolite powder was then activated using thermal activation at a temperature of 400^O C for 4 hours and then was placed in the desiccator for cooling. The thermally activated zeolite then was activated using hydrothermal activation i.e by heating it in 2.5 N NaOH solution at 100^O C for 12 hours. The hydrothermally activated zeolite was cooled and then leached with H_2O for several times until all excess NaOH in was removed. The activated zeolite was dried at 200^{o}C for 4 hours and it was then placed in a desiccator for cooling; b) Montmorillonite was prepared by drying (air-dried) it and then it was grounded to be powder and sieving to pass through a 100-mesh diameter sieve; c). Rice husk was prepared by drying (air-dried) and grounding to be powder and sieving to pass through a 100-mesh diameter sieve; d). these materials (activated zeolite, urea, adhesive material) then blended by adding the water in an amount of 30 % w/w and the proportion of adhesive material (montmorillonite and rice husk 1:1) in the amount of 0, 3, 6, 9, 12 % w/w. The mixture of these materials then granulated and sieving to pass through 2.0 – 2.5 mm and 2.5 – 3.0 mm diameter sieve and then drying so that it is ready to be tested.

The experiment was laid out based on the completely randomized design with 3 replications, consisting of two factors i.e. fertilizer granule size (2.0 – 2.5 mm and 2.5 – 3.0 mm) and fertilizer adhesive material proportions (0, 3, 6, 9, 12 % w/w), generating 10 combinations of NZEO-SR fertilizers. The fertilizers were tested in both water and soil media. The treatment combinations were depicted in Table 1.

Fertilizer test in a water medium to measure water penetration

Each type of 10 NZEO-SR fertilizers was tested in an aqueous medium using aquadest in petridish, with a ratio of fertilizer: aquadest 1: 1. Each petridish was filled 10 granules of fertilizer and aquadest. It was then daily observed to calculate the percentage of fertilizer granules that was dissolved. After all, fertilizers dissolved, the solution in each petridish was analyzed to measure: a). water penetration (time of fertilizer to completely dissolve); b). N-available (double distillation, NH4 + and NO3-); c). pH-H2O (fertilizer ratio: aquadest 1: 5); and d). DHL (fertilizer ratio: aquadest 1: 5)

Testing of Fertilizer in the soil medium

Each type of 10 NZEO-SR fertilizers was tested in soil medium in the pot using ultisols as media. Each pot was filled 5 kg oven-dried soil and fertilizers in the amount of 60 kg N/ha. it then pours aquadest to kept soils in field capacity. After 1 month incubation, the soil in each pot was analyzed to measure: a). N-available (double distillation, NH_4^+ and NO_3^-); c). pH-H_2O (soil: aquadest 1: 5 w/w); and d). DHL (soil: aquadest 1: 5 w/w). The observed variables data were analyzed using analysis of variance followed by the Duncan's Multiple Range Test at $P < 0.05$ %.

RESULTS AND DISCUSSION

Fertilizer test in a water medium

Results of the experiment on testing of fertilizer NZEO-SR in water medium indicated that the fertilizer granule diameter size of 2.0 – 2.5 mm in combination with 3 % (w/w) adhesive showed the greatest water penetration retention at the same fertilizer granule size. The fertilizer was damaged after 63.8 minutes of immersion in aquadest (Table 2). The research also showed that the water penetration retention decreased as the proportion of adhesive increased. The fertilizer breakdown time is measured as the time required for the fertilizer to undergo 100% damage (fertilizer completely dissolve).

Table 1. Combinations of treatments in the fertilizer adhesive and granule size experiment

Fertilizer adhesive levels (TBP)	Granule size (UP)	
	UP_1	UP_2
TBP_o	UP_1-TBP_o	UP_2-TBP_o
TBP_1	UP_1-TBP_1	UP_2-TBP_1
TBP_2	UP_1-TBP_2	UP_2-TBP_2
TBP_3	UP_1-TBP_3	UP_2-TBP_3
TBP_4	UP_1-TBP_4	UP_2-TBP_4

UP_1: Fertilizer granule size with diameter 2.0 – 2.5 mm, UP_2: Fertilizer granule size with diameter 2.5 – 3.0 mm; TBP_o, TBP_1, TBP_2, TBP_3, TBP_4 = Fertilizer adhesive rates 0, 3, 6, 9, 12 % (w/w), respectively.

The increase in fertilizer adhesive proportions from 6, 9 to 12 %, significantly decreased the fertilizer breakdown time to 9.60; 15.50 and 15.1 minutes, respectively, while fertilizers without an adhesive took 18.1 minutes to break down (Figure 1).

Results of the experiment also showed that fertilizer NZEO-SR of a granule diameter of 2.5 – 3.0 mm in combination with various proportions of adhesive had lower water penetration retention as compared with the smaller granules (2.0-2.5 mm). The fertilizer granules with a larger diameter will have a bigger number of adhesive materials so that the fertilizers granules with a diameter of 2.5 – 3.0 mm have a higher capability of holding NZEO-SR component compared to the fertilizers granules with a smaller diameter (2.0 – 2.5 mm). The fertilizer granule with a diameter of 2.5-3.0 mm in combination with fertilizer adhesive material of 3% (w/w) exhibited the longest fertilizer breakdown time (87.8 minutes) indicative of the highest water penetration retention (Table 2). At the same granule size, the relatively high water penetration retention was also found in the applications of 6 and 9% adhesive materials (44.7 and 49.5 minutes, respectively) (Table 2, Figure 1 and 2). Fertilizers with high water penetration retention were expected to exhibit high N use efficiency as the fertilizers were not easily dissolved and retention of nitrogen is still in place for a longer time so that they were potential to be utilized as a slow release fertilizer.

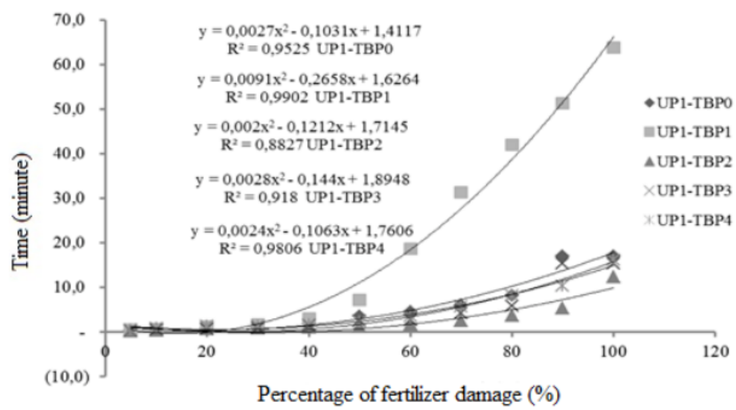

Figure 1. The relation between time and percentage of fertilizer damage at a granule diameter of 2.0-2.5 mm

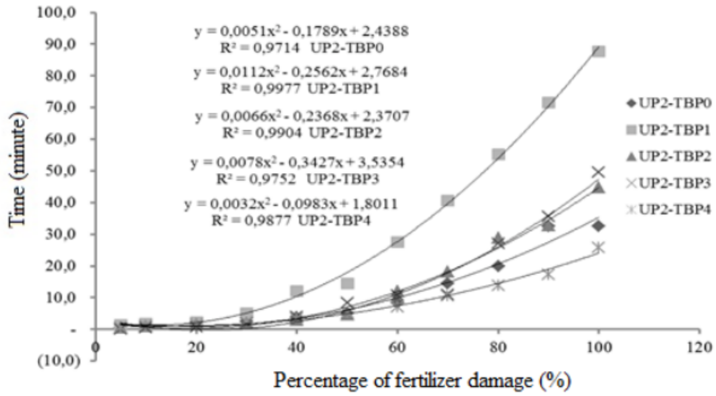

Figure 2. The relation between time and percentage of fertilizer damage at a granule diameter of 2.5-3.0 mm

Table 2. Fertilizer breakdown time as affected by adhesive rates and granule diameter

No.	Treatments	Breakdown time	
		Minutes	Seconds
1.	UP1-TBP0	18	6
2.	UP1-TBP1	63	47
3.	UP1-TBP2	9	36
4.	UP1-TBP3	15	30
5.	UP1-TBP4	15	8
6.	UP2-TBP0	32	35
7.	UP2-TBP1	87	45
8.	UP2-TBP2	44	40
9.	UP2-TBP3	49	30
10.	UP2-TBP4	23	58

UP_1: Fertilizer granule size with diameter 2.0 – 2.5 mm, UP_2: Fertilizer granule size with diameter 2.5 – 3.0 mm; TBP_o, TBP_1, TBP_2, TBP_3, TBP_4 = Fertilizer adhesive rates 0, 3, 6, 9, 12 % (w/w), respectively.

The analysis of variance indicated that applications of adhesives gave significant effects on electrical conductivity (EC), pH (H_2O), and dissolved N. The fertilizer granule diameter did not give significant effects on all variables except for dissolved N (Table 3). The EC and pH (H_2O) values increased as the adhesive proportions were increased. Applications of fertilizer adhesive material at rates ranging from 3 to 12 % (w/w), increased the solution pH (H_2O) to 8.96 - 9.25 or equivalent to a pH increase of 2.75 to 6.08 %, respectively, as compared to the control (without adhesive) (Table 4).

NZEO-SR is a fertilizer having an alkaline reaction as it is mainly composed of base cation-rich zeolite. As indicated by Table 3, pH(H_2O) of the solution increased with an increase in EC indicating that more base cations were released to the solution. The applications of adhesive material up to 12% resulted in EC values ranging from 182.58 to 204.18 µS cm^{-1} or equivalent to an increase ranging from 18.18 to 32.90 % (Table 5). The significant EC rise might have been attributable to the release of base cations from the zeolites and the adhesive material (montmorillonite mineral).

The applications of fertilizer adhesive up to 12% (w/w) were conversely related with dissolved N. The applications of fertilizer adhesive between 3 and 12% (w/w) resulted in an increase of dissolved N between 135.9 and 203.6 equivalent to 9,59 and 39,65 % increase (Table 6). The reduced dissolved N can be attributable to the increase in adsorbed N onto exchange sites of the adhesive material which was mainly montmorillonite clay mineral. Montmorillonite is a mineral known to have high cation exchange capacity.

Table 3. Variance analysis of water chemical properties as affected by NZEO-SR with various combinations of adhesive and granule size in a water medium

Source of variance	Water chemical properties			
	pH (H_2O)	EC	Dissolved N	Total N
Treatment				
Fertilizer adhesive rates (P)	**	**	**	ns
Fertilizer granule diameter (D)	ns	ns	**	ns
Interaction				
PxD	ns	ns	ns	ns

**: Significant at P<0.01

Table 4. Solution pH (H_2O) values at various levels of fertilizer adhesive and granule diameter in a water medium

Fertilizer adhesive rates (P) (%)	Granule diameter (D)		Mean-P	Difference D
	2.0 - 2.5 mm	2.5 - 3.0 mm		
0	8.67 c	8.68 c	8.72 c	0.08 ns
3	9.23 a	8.99 b	9.11 ab	0.24 ns
6	8.97 bc	8.96 b	8.96 b	0.01 ns
9	9.26 a	9.25 a	9.25 a	0.01 ns
12	9.11 ab	9.08 ab	9.10 ab	0.03 ns
Mean	9.06	8.99	9.03	(-)

Numbers in the same column followed by the same letter were not significant at P<0.05 of DMRT; (-) = No interaction; ns = not significant

Table 5. EC values (µS cm^{-1}) at various proportions of fertilizer adhesive and granule diameter in a water medium

Fertilizer adhesive rates (P) (%)	Fertilizer diameter (D)		Mean	Difference
	2.0 - 2.5 mm	2.5 - 3.0 mm		
0	151.47 b	155.80 cd	153.63 b	-4.33 ns
3	197.53 a	210.83 a	204.18 a	-13.30 ns
6	175.67 ab	189.50 ab	182.58 a	-13.83 ns
9	148.77 b	138.40 d	143.58 b	10.37 ns
12	190.43 a	176.87 bc	183.65 a	13.57 ns
Mean	172.77	174.28	173.53	-1.51 ns

Numbers in the same column followed by the same letter were not significant at P<0.05 of DMRT; (-) = No interaction; ns = not significant

Table 6. Dissolved N (ppm N) at various proportions of fertilizer adhesive and granule diameter in a water medium

Fertilizer adhesive rates (P) (%)	Granule diameter (D) 2,0 - 2,5 mm	Granule diameter (D) 2,5 - 3,0 mm	Mean	Difference
0	260.2 a	190.2 a	225.2 a	70.0 ns
3	240.3 a	166.8 a	203.6 a	73.5 ns
6	180.8 a	182.0 a	181.4 ab	-1.2 ns
9	175.0 a	160.7 b	176.9 b	14.3 ns
12	165.7 a	106.2 ab	135.9 bc	59.5 ns
Mean	204.4	161.2	182.8	43.2 **

Numbers in the same column followed by the same small letter were not significant at P<0.05 of DMRT;
** = significant at 1% level; ns = not significant

Table 7. Total N (%) at various proportions of fertilizer adhesive and granule diameter in a water medium

Fertilizer adhesive rates (P) (%)	Granule diameter (D) 2.0 - 2.5 mm	Granule diameter (D) 2.5 - 3.0 mm	Mean	Difference
0	0.16 ab	0.20 a	0.18 a	-0.04 ns
3	0.20ab	0.26 a	0.23 a	-0.06 ns
6	0.20 ab	0.20 a	0.20 a	-0.00 ns
9	0.19 ab	0.19 a	0.19 a	0.00 ns
12	0.25 a	0.22 a	0.24 a	0.04ns
Mean	0.20	0.21	0.21	-0.01 ns

Numbers in the same column followed by the same small letter were not significant at P<0.05 of DMRT;
ns = not significant

Table 8. Variance analysis of some soil chemical properties as affected by NZEO-SR made from various combinations of adhesive and granule size in the soil medium

Source of variance	Soil chemical properties			
	pH (H_2O)	DHL	Available N	Total N
Treatment				
Fertilizer adhesive level (P)	*	ns	ns	*
Fertilizer granule diameter (D)	ns	ns	ns	ns
Interaction				
PxD	ns	ns	ns	ns

*: Significant at P<0.05

Table 9. pH (H_2O) values at various rates of fertilizer adhesive and granule diameter in the soil medium

Fertilizer adhesive rates (P)	Granule diameter (D) 2.0 - 2.5 mm	Granule diameter (D) 2.5 - 3.0 mm	Mean	Difference
0	5.15 b	5.13 a	5.14 b	0.03 ns
3	5.44 a	5.24 a	5.34 a	0.20 ns
6	5.44 a	5.31 a	5.38 a	0.13 ns
9	5.16 b	5.30 a	5.23 ab	-0.13 ns
12	5.29 ab	5.27 a	5.28 ab	0.03 ns
Mean	5.30	5.25	5.27	0.05 ns

Numbers in the same column followed by the same small letter were not significant at P<0.05 of DMRT;
ns = not significant

Table 10. EC (µS cm^{-1}) values at various proportions of fertilizer adhesive and granule diameter in a water medium

Fertilizer adhesive rates (P) (%)	Granule diameter (D) 2.0 - 2.5 mm	Granule diameter (D) 2.0 - 2.5 mm	Mean	Difference
0	60.87 ab	61.37 a	61.12 ab	-0.50 ns
3	67.83 ab	62.20 a	65.02 ab	5.63 ns
6	67.63 ab	76.01 a	71.82 ab	-8.37 ns
9	69.33 ab	65.87 a	67.60 ab	3.47 ns
12	81.93 a	63.83 a	72.88 a	18.10 ns
Mean	69.52	65.85	67.69	3.67 ns

Numbers in the same column followed by the same small letter were not significant at P<0.05 of DMRT;
ns = not significant

Table 11. Soil available N (ppm N) at various proportions of fertilizer adhesive and granule diameter

Fertilizer adhesive rates (P) (%)	Granule diameter (D) 2.0 - 2.5 mm	Granule diameter (D) 2.0 - 2.5 mm	Mean	Difference
0	146.5 a	121.0 a	133.8 a	25.5 ns
3	145.2 a	112.7 a	129.0 a	32.4 ns
6	122.8 ab	123.9 a	123.3 a	-1.1 ns
9	131.9 ab	132.4 a	132.1 a	-0.5 ns
12	112.8 ab	128.9 a	120.9 a	-16.2 ns
Mean	131.8	123.8	127.8	8.0 ns

Numbers in the same column followed by the same small letter were not significant at P<0.05 of DMRT;
ns = not significant

Table 12. Total N (%) at various proportions of fertilizer adhesive and granule diameter in the soil medium

Fertilizer adhesive rates (P) (%)	Granule diameter (D) 2.0 - 2.5 mm	Granule diameter (D) 2.0 - 2.5 mm	Mean	Difference
0	0.17 b	0.17 a	0.17 c	0.00 ns
3	0.22 b	0.17 a	0.19 bc	0.05 ns
6	0.26 b	0.22 a	0.24 abc	0.04 ns
9	0.33 ab	0.30 a	0.32 ab	0.04 ns
12	0.46 a	0.22 a	0.34 a	0.24 ns
Mean	0.29	0.22	0.25	0.07 ns

Numbers in the same column followed by the same small letter were not significant at P<0.05 of DMRT;
ns = not significant

As depicted in Table 7, the addition of fertilizer adhesive and granule diameter of NZEO-SR fertilizer did not affect the total N of the solution. Applications of adhesive at a rate between 0 and 12 % (w/w) gave the total N between 0.18 and 0.24%. The adhesive materials did not affect the total N as the materials contained very small amounts of N, thus they have a very little contribution to total N.

Testing of Fertilizer in the soil medium

The analysis of variance indicated that applications of fertilizer adhesive gave significant effects on pH (H_2O) and soil total N, but did not affect the EC and soil available N. The fertilizer granule diameter did not give significant effects on all soil chemical properties (Table 8). There was an average increase of soil pH (H_2O) of 0.62 points with the applications of fertilizer adhesive at rates between 3 and 12 %

(w/w). The increase in pH could be attributed to carbonate ions contained in the montmorillonitic adhesive materials.

As depicted in Table 9 and 10, the increase in pH was not followed by the increase in EC values. The EC values were not significantly affected by increasing rates of fertilizer adhesive indicating that the applications of adhesive contributed only a negligible amount of cations to the soil solution. Applications of adhesive materials between 3 and 12% (w/w) resulted in EC values between 65.02 and 72.88 µS cm^{-1}, slightly higher as compared to the control treatment (61.12 µS cm^{-1}) (Table 10). Table 11 showed that the applications of adhesive materials between 3 and 12% (w/w) did not affect the soil available N. Applications of adhesive materials between 3 and 12% (w/w) resulted in soil available N between 120.9 and 132.1 ppm N. These values were comparable to the control treatment (133.8 ppm). Soil available N is greatly determined by NH_4^+ ions adsorbed in the exchange sites of zeolite in NZEO-SR fertilizer, thus adhesive materials did not have a significant effect on the NH_4^+ release from zeolite exchange sites (Table 10).

The applications of adhesive materials gave a significant effect on soil total N. Applications of adhesive materials between 3 and 12% (w/w) resulted in soil total N between 0.19 and 0.34 % equivalent to an increase between 1.18 and 100%, respectively, as compared to the control treatment (Table 12). The adhesive material used in this research was montmorillonite clay taken from Vertisol soils. This type of clay (type 2:1) has huge negatively charged sites thus it has very high cation exchange capacity. These characteristics enable the clay to adsorb NH_4^+ ions liberated from NH_4^+-loaded zeolite in NZEO-SR fertilizer, thus preventing them from N losses through leaching and gaseous losses via ammonia volatilization and denitrification (Kithome, Paul, Lavkulich, & Bomke, 1998; Park & Komarneni, 1998).

Zeolite is an alumino-silicate mineral having capability of adsorbing and exchanging cations such as NH_4^+. The characteristics are formed as zeolite structure exhibits negatively-charged sites on the surfaces of its nano-sized pore channels. Therefore, the ammonium ions liberated from urea hydrolysis or other mechanisms like organic matter decomposition can be adsorbed temporarily. This mechanism prevents the NH_4^+ ions from leaching and gaseous losses (van straaten, 2002). For this reason, zeolite has the potential to be used as slow-release fertilizer (Sepaskhah & Barzegar, 2010; Sepaskhah & Yousefi, 2007; Torma, Vilcek, Adamisin, Huttmanova, & Hronec, 2014; Vilcek, Torma, Adamisin, & Hronec, 2013). The NH_4^+ adsorption capacity of zeolite is greatly affected by high ion concentrations and the presence of other cations like Mg^{2+} in soil solution (Ganrot, Dave, & Nilsson, 2007; Putra, Mursanto, & Handayani, 2014).

CONCLUSIONS

1. NZEO-SR fertilizer with a granule diameter 2,5 – 3,0 mm in a combination of fertilizer adhesive at 3% (w/w) had the highest water penetration retention.
2. Fertilizer adhesive montmorillonite increased pH (H_2O), electrical conductivity and dissolved N.
3. Fertilizer granule size did not affect all variables both in water and soil media.
4. In soil media, adhesive material incorporated in NZEO-SR fertilizer increased soil pH (H_2O) and total soil N but did not affect the soil electrical conductivity and available N.

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