Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2023.v28i3.99-106

Release Pattern of Nitrogen and Potassium from Controlled Release Fertilizer (CRF) in the Soil

Suwardi[1,3*], Dyah Tjahyandari Suryaningtyas[1,3], Hens Saputra[2], Mochamad Rosjidi[2], Anwar Mustafa[2] and Abdul Ghofar[2]

[1]Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Bogor 16680, Indonesia
[2]The National Research and Innovation Agency, Jakarta Pusat 10340, Indonesia
[3]Center for Mine Reclamation Studies, The Institute of Research and Community Service, IPB University, Jalan Raya Pajajaran, Baranangsiang IPB Campus, Bogor 16144, Indonesia
**e-mail: suwardi-soil@apps.ipb.ac.id*

Received 20 February 2023, Revised 03 March 2023; Accepted 10 April 2023

ABSTRACT

Nitrogen (N) and potassium (K) are essential macronutrients that significantly influence plant growth and yield. However, their availability in the soil is often reduced due to losses through volatilization, denitrification, leaching, and plant uptake. To enhance nutrient efficiency and minimize these losses, Controlled Release Fertilizers (CRFs) have been developed as a promising alternative to conventional fertilization methods. This study aimed to evaluate the release dynamics of ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and potassium (K) from CRFs using a laboratory incubation approach. Two types of CRFs - CRF A (16-16-16) and CRF B (30-6-8) were tested alongside a conventional non-CRF fertilizer (Mutiara NPK 16-16-16) as the control. Each treatment was applied at two dosage levels: 600 kg ha^{-1} and 1200 kg ha^{-1}. The results revealed that NH_4-N release was initially high (40–60%) but decreased to nearly zero by the 14th week. NO_3-N exhibited a moderate initial release (17–40%) during the first week, followed by a consistent increase, reaching nearly 100% by Week 14. Potassium release started at 20–30% in the first week and increased to 30–70% by the end of the incubation period. Notably, CRF B (30-6-8) applied at 1200 kg ha^{-1} demonstrated the slowest nitrogen release rate, indicating its potential for prolonged nutrient availability. This study contributes to the understanding of nutrient release kinetics in CRFs and supports their application in optimizing fertilizer use efficiency for sustainable agricultural practices.

Keywords: Ammonium nitrogen (NH_4-N), Controlled Release Fertilizer (CRF), nitrate nitrogen (NO_3-N), potassium

INTRODUCTION

Nitrogen (N) is an essential element that plants need in large quantities, but its availability in the soil is usually small (Krapp, 2015). To overcome this lack of N in the soil, farmers apply it in the form of N fertilizer. However, the efficiency of N fertilizer is relatively low; only about 30-40% of N is absorbed by plants, and the remaining 60-70% is otherwise lost. This loss of N is due to deprotonation of NH_4^+, volatilization of NH_3 gas to the atmosphere, loss via the nitrification, and then leach and runoff due to the poorly bound nature of anion NO_3^- to the soil, also N losses through denitrification (Gu and Yang, 2022). Of the nutrients naturally deficient in the soil, N plays the most critical role in realizing the maximum potential of crop yield.

Plants absorb N as NH_4-N and NO_3-N, resulting from ammonification and nitrification (Li et al., 2013). The presence of these two compounds is a key determinant of the availability of N nutrients to meet the needs of plants throughout their growth period. The nitrate ion is negatively charged, so negatively charged soil particles cannot adsorb it; it becomes very mobile, highly soluble, cannot bind or be absorbed by the soil layers, and is undetectable in water (El-Nahas et al., 2019).

Potassium is likewise an essential plant nutrient, as it is essential in various metabolic processes (El-Beltagi et al., 2020). Potassium is absorbed by plants in the form of K^+, and many sources of K are available in soils or provided as fertilizers (Hasanuzzaman et al., 2018). Soil K loss can occur through leaching because it is easily soluble in water. Runoff quickly leaches the soil available K (Sardans and Peñuelas, 2015). Furthermore, if there is a large amount of K in the soil, potassium would be absorbed by plants also in excess amounts. This excess in K absorption by plants can harm plant performance and growth by inhibiting the uptake of other vital nutrients such as N, Mg, or iron (Xu et al., 2020). Conversely, K deficiency can reduce chlorophyll and significantly inhibit photosynthesis due to leaf chlorosis (Qi *et al.*, 2019). Hou et al. (2019) stated that the combined application of N and K showed higher grain yield than the sole application of either N or K.

Due to the quick release of nitrogen from urea fertilizer, plants cannot access up to 40 – 70% of this N in the soil. One method of reducing nitrogen losses involves using controlled-release fertilizers (CRF). The coated urea was a highly effective nitrogen fertilizer due to the controlled release by regulation coating (Chen et al., 2020). (Beig et al., 2020) also stated that to overcome this problem, a polymer coating on ordinary urea fertilizer can be utilized to enhance its efficiency by slowing down the release rate of N in soil. The slow-release technique is the latest and highly developed method of feeding plants with a reliable source of vital nourishment. In short, the efficiency of N and K fertilization can be substantially boosted through the formulation of Slow Release Fertilizers (SRF) and Controlled Release Fertilizers (CRF) or a combination of both (S/CRF). As implied, SRF and CRF can optimize N absorption by plants by regulating the release of N to synchronize it with the time and amount needed by plants and keep it longer in the soil. The use of controlled-release fertilizer (CRF) can have a positive effect on potassium absorption in soil. Tian et al. (2017) found that due to the continuous release of potassium from CRF, the content of soil available potassium increased significantly. The mechanism of CRF not only decreases potassium loss due to volatilization and leaching but also provides a precisely appropriate amount of nutrients to plants. CRF coating can be done by mixing urea with specific compounds to form granules. A suitable material for CRF coating is one that has a high cation exchange capacity (CEC), such as zeolite. Soltys et al. (2020) stated that zeolites accumulate essential nutrients for plants, such as N and K, in the form of exchangeable cations and adsorb NH_3, and then slowly give them away during plant growth, thereby acting as a prolonger of plant nutrient source. Furthermore, the mobile form of fertilizers adsorbed by zeolite is retained from leaching, thereby reducing the loss of ammonium nitrogen by nitrification and evaporation and improving plant nutrition with N and K.

In summary, the advantages of CRF over conventional fertilizers include regulated and timely but ample fertilizer supply; reduced NO_3-N leaching; lower fertilizer doses that are needed to be applied by farmers; more significant N accumulation in plant tissues; hastened mineralization; and higher organic N content in the soil. In the long run, it can significantly reduce production costs by promoting fertilization efficiency (Daza et al., 2015). Plant growers use repeated applications of N, P, and K fertilizers to achieve desired higher crop yields. Consequently, this practice can lead to an undesirable decline in soil fertility by increasing salt concentrations, thereby causing instead, future crop losses (Zulfiqar et al., 2019). That problem was solved by using zeolite as a carrier of CRF because zeolite has a positive effect on increasing plant height and root weight. The increase in root weight is used as an indicator of nutrient uptake ability. The greater weight of plant roots, the higher the ability of roots to absorb nutrients, so plants can grow better and produce higher (Suwardi dan Wijaya 2013). In Indonesia, CRF is fast becoming a practical and sustainable solution to significant problems in agricultural production.

The objective of this study was to analyze NH_4-N and NO_3-N release patterns from CRF so that it can provide valuable information on nutrient release and leaching in soil and help improve the efficiency of fertilizer use in agriculture.

MATERIALS AND METHODS

This research was conducted from November 2017 to March 2018 at the Laboratory of the Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University. The incubation treatment and soil chemical analyses were conducted at the University's Laboratory of Chemistry and Soil Fertility.

Preparation of test fertilizer and soil

This study used two Controlled Release Fertilizers (CRF) containing different N, P, and K percentage levels, namely: CRF A (16-16-16) and CRF B (30-6-8). The preparation of the CRF fertilizer in this study used a fertilizer formulation that included urea, DAP, and KCl, and added with zeolite. Zeolite is a mineral that functions to slow down the process of changing ammonium ions so that they do not quickly become nitrate ions. Zeolite

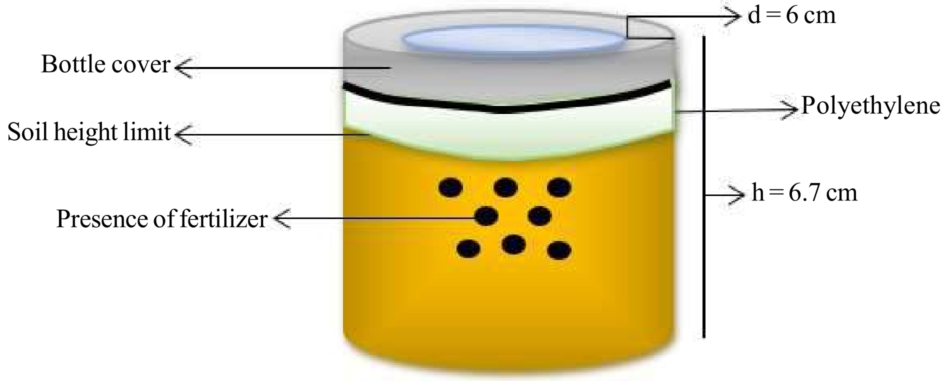

Figure 1. Illustration of an incubation bottle containing the experimental soil and fertilizer kept under incubation over 14 weeks.

is a supporting material for slow-release substances used by utilizing the surface area of zeolite and its absorption ability (Evi et al., 2017). The addition of zeolite as a coating to CRF can be done by mixing zeolite with the other ingredients of CRF. The difference between the two CRF types is the type of zeolite used. CRF (30-6-8) contains 135.1 g zeolite 13, while CRF (16-16-16) contains 167.5 g zeolite 11. For Control, the non-CRF used was Mutiara NPK (16-16-16) fertilizer. Epiaquept soil was sourced from the Situ Gede area (6°33'4.81"S, 106°44'37.85" E), the land of which is usually planted with lowland rice. Experimental soil was taken at a depth of 0-20 cm from one point on one-fourth of the paddy field plot and then air-dried. The collected soil samples are about 1 kg. For the analysis of its chemical properties in the laboratory, the soil was ground and sifted to pass a 2-mm sieve.

Soil Incubation in the Laboratory

The fertilizer release rate was measured utilizing the incubation method in an open space in the laboratory. Some 111.96 g of air-dried soil, or equivalent to 100 g of absolute dry weight with a soil moisture content of 11.96%, was put into a cylindrical plastic container with a diameter of 6.00 cm and a height of 6.70 cm (Figure 1). The treatments consisted of 3 types of fertilizer, each with two doses (Table 1). Each fertilizer treatment was added to the soil in the incubation bottle. Each soil fertilizer mix was then given 30 ml water to attain field capacity water content (48.29%). All incubation bottles were also covered with insulated polyethylene plastic.

Incubation was carried out at room temperature in an open space for 14 weeks with successive measurement and analysis of NH_4-N and NO_3-N, potassium, and soil water content carried out at Weeks 1, 2, 3, 4, 6, 8, 10, 12, and 14.

The CRF (Controlled Release Fertilizer) used in this study contained Urea, DAP (Diammonium phosphate), KCl (potassium chloride), and zeolite (serving as coating material). The addition of zeolite in the formulation of CRF can lessen the solubility of NPK in the soil (Agustina et al., 2018). Zeolite 13 and 11 were used for CRF B (30-6-8) and CRF A (16-16-16), respectively. The form of fertilizer used in this study is granule. The fertilizer is above the soil and below the polyethylene; for more details, see (Figure 1).

Table 1 Treatment combinations (fertilizer type and dose).

Treatment	Fertilizer	
	Name	Dose (mg per bottle)
A1	CRF A (16-16-16)	0.3
A2	CRF A (16-16-16)	0.6
B1	CRF B (30-6-8)	0.3
B2	CRF B (30-6-8)	0.6
M1	MUTIARA NPK (16-16-16)	0.3
M2	MUTIARA NPK (16-16-16)	0.6

Data Processing

Based on the concentration values (in mg kg^{-1}) derived from the NH_4-N, NO_3-N, and K-Bray 1 formulas, respectively, the ppm values (in terms of mg 100 g^{-1}) were obtained. The graphs of the pattern of the release of NH_4-N and NO_3-N show the relationship between their respective concentrations released into the soil divided by the total concentration of N applied to the soil. Same as nitrogen, the graphs of the pattern of the release of K^+ show the relationship between K^+ concentrations released into the soil divided by the total concentration of K applied to the soil.

RESULTS AND DISCUSSION

The pattern of NH_4-N and NO_3-N Release from CRF

The trend in ammonium N and nitrate N release from among the six treatment combinations over the 14-week incubation period is presented in Figure 2. After the first week, NH_4-N release ranged from 40 to 63%, then gradually declined to approach 0% in the 14^{th} week. Comparable results were reported by Nainggolan (2010) - the release of NH_4-N decreased with incubation to 0% at Week 14, in which the CRF was composed of urea and zeolite. However, Nainggolan's data ranged only from 12 to 33%, indicating a significantly slower rate of nutrient release than this study. In contrast, until the 14th week, the CRF fertilizer treatment only with zeolite has yet to release all NH_4-N. It is likely because zeolite plays a vital role in helping bind NH_4-N to the lattice, and as a result, NH_4-N is not readily released into the soil. The main advantages of zeolite are very high CEC between 80 to 180 cmol (+) kg^{-1} and its ability to adsorb ammonium ions of 3.5 g kg^{-1}. The ability of the zeolite to absorb ammonium ions due to cavity zeolite has the same size as ammonium ions, around 0.2 – 0.3 mm (Suwardi, 2004).

The greater the number of exchange lattices in the zeolite, the greater the amount of NH_4-N derived from urea fertilizer in the CRF formula hydrolyzed into ammonium ions, thereby adsorbed by the lattice. The ammonium ion adsorbed by the zeolite is not released into the soil solution for as long as the ammonium ion remains high. When the ammonium ions in the soil have turned into nitrate ions, the stock of ammonium ions in the zeolite cavity is released into the soil solution (Jakkula & Wani, 2018).

The application of B2 fertilizer (CRF B (30-6-8) at a dose of 1200 kg ha-1 showed the lowest NH4-N release rate compared to the other fertilizers, as depicted by the purple curve in Figure 2. In the first week, the two CRFs quickly turned into NH_4-N through the ammonification process so that the ammonium ion would show a high value in the first week. The ammonium ion produced from the ammonification process is immediately converted into nitrate ion through nitrification. Abatenh et al. (2018) stated that the first stage involved obligate autotrophic bacteria known as Nitrosomonas with the yield of nitrite ions:

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+$$

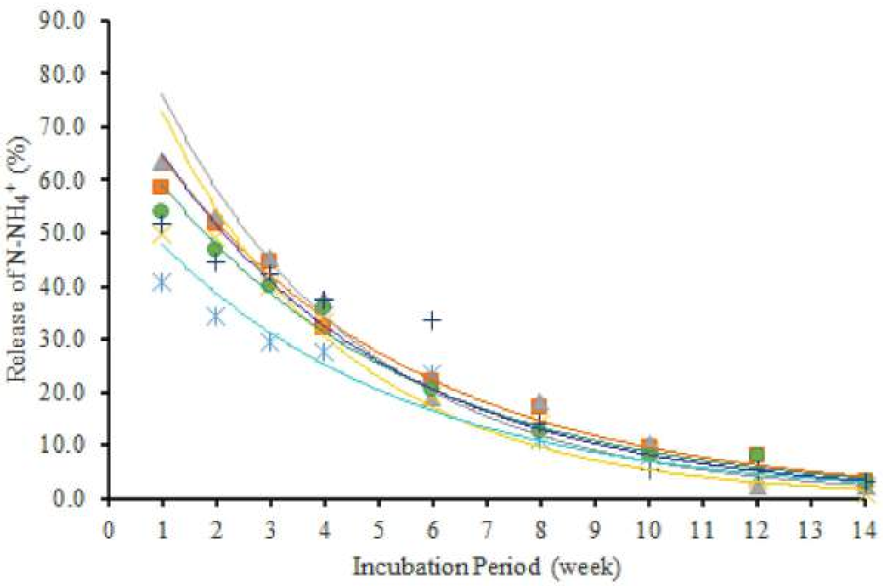

Figure 2. Release of NH_4-N (%) into the soil from the 6 treatments over 14 weeks of incubation. —■— : A1, —▲— : A2, —✱— : B1, —✱— : B2, —●— : M1, +: M2.

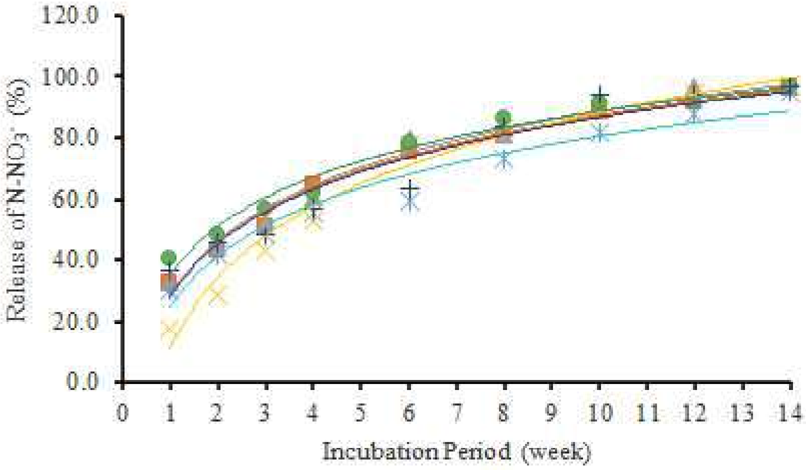

Figure 3. Release of NO_3-N (%) into the soil from the 6 treatments over 14 weeks of incubation. —■—: A1, —▲—: A2, —✕—: B1, —✳—: B2, —●—: M1, +: M2.

The conversion of nitrite ions to nitrate ions involves obligate autotrophic bacteria known as Nitrobacteria:

$$2NO_2^- + O_2 \longrightarrow 2NO_3^-$$

The activity of Nitrosomonas and Nitrobacteria increases the amount of nitrate in the soil formed through the nitrification process. However, this nitrification process can only occur under conditions of sufficient oxygen (aerobic), so the nitrate ions multiply in unison with incubation time.

Figure 3 shows the nitrogen nitrate (NO_3-N) release pattern from CRF fertilizer over the 14-week incubation period. In the first week, it amounted to 17 – 40%, then went up in the following weeks, finally approaching 100% by Week 14. Similar findings were reported by Nainggolan (2010). The loss of the nitrate ions is due to washing while the ammonium ions are evaporated into the air.

As stated above, the results of this study are consistent with the findings of Nainggolan (2010). The level of NO_3-N release in this study was close to 100% at Week 14, particularly in the case of the CRF without humic acid. This happened because, without a regulating agent, such as humic acid, the tested CRF fertilizer formulation was inefficient in holding nitrogen, so a coating from CRF would be needed to slow down the release of NO_3-N (Hidayatussittah, 2018). A cavity in the zeolite structure has a size that follows ammonium ions, so the absorption of the zeolite to ammonium is high (Suryaningtyas et al., 2023). The ability of zeolite to absorb ammonium causes the change of ammonium ions to nitrate ions or to evaporate as ammonia gas will be inhibited. With this mechanism,

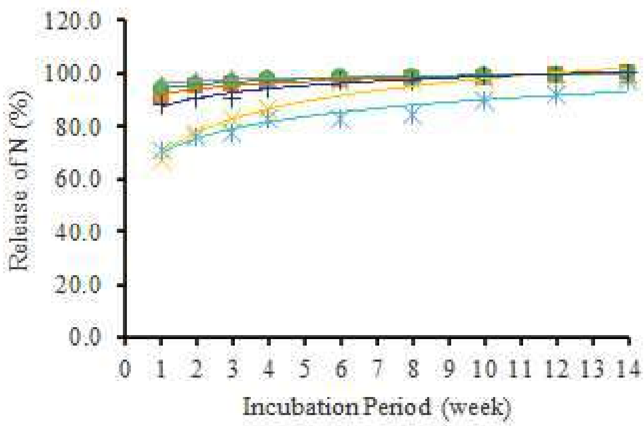

Figure 4. Nitrogen release (%) into the soil from the 6 treatments over 14 weeks of incubation. —■—: A1, —▲—: A2, —✕—: B1, —✳—: B2, —●—: M1, +: M2.

nitrogen loss in the form of nitrate can be pressed so nitrogen loss can be reduced (Suwardi, 2007).

In summary, the three types of fertilizers tested in this study, in order of release from lowest to highest, were CRF B (30-6-8) (B1 and B2), CRF A (16-16-16) (A1 and A2), and Mutiara NPK (16-16-16) (M1 and M2) (Figure 3).

The pattern of nitrogen release from the six treatments in this study over the 14 weeks of incubation is presented in Figure 4. CRF B (30-6-8) showed a lower rate of release (60 – 70% in the first week) compared to CRF A (16-16-16) and Mutiara NPK (16-16-16), which released around 80 – 90% each. Ranked from lowest to highest N release rate were CRF B (30-6-8) (B1 and B2), Mutiara NPK (16-16-16) (M1 and M2), and CRF A (16-16-16) (A1 and A2). At Week 14, nitrogen release reached 100% for CRF A (16-16-16) and Mutiara NPK (16-16-16), while for CRF B (30-6-8), it was comparatively less. It implies that CRF B (30-6-8) was able to slow down the release of nitrogen. In other words, CRF B (30-6-8) managed to effectively keep the presence of nitrogen in the soil even up to 14 weeks.

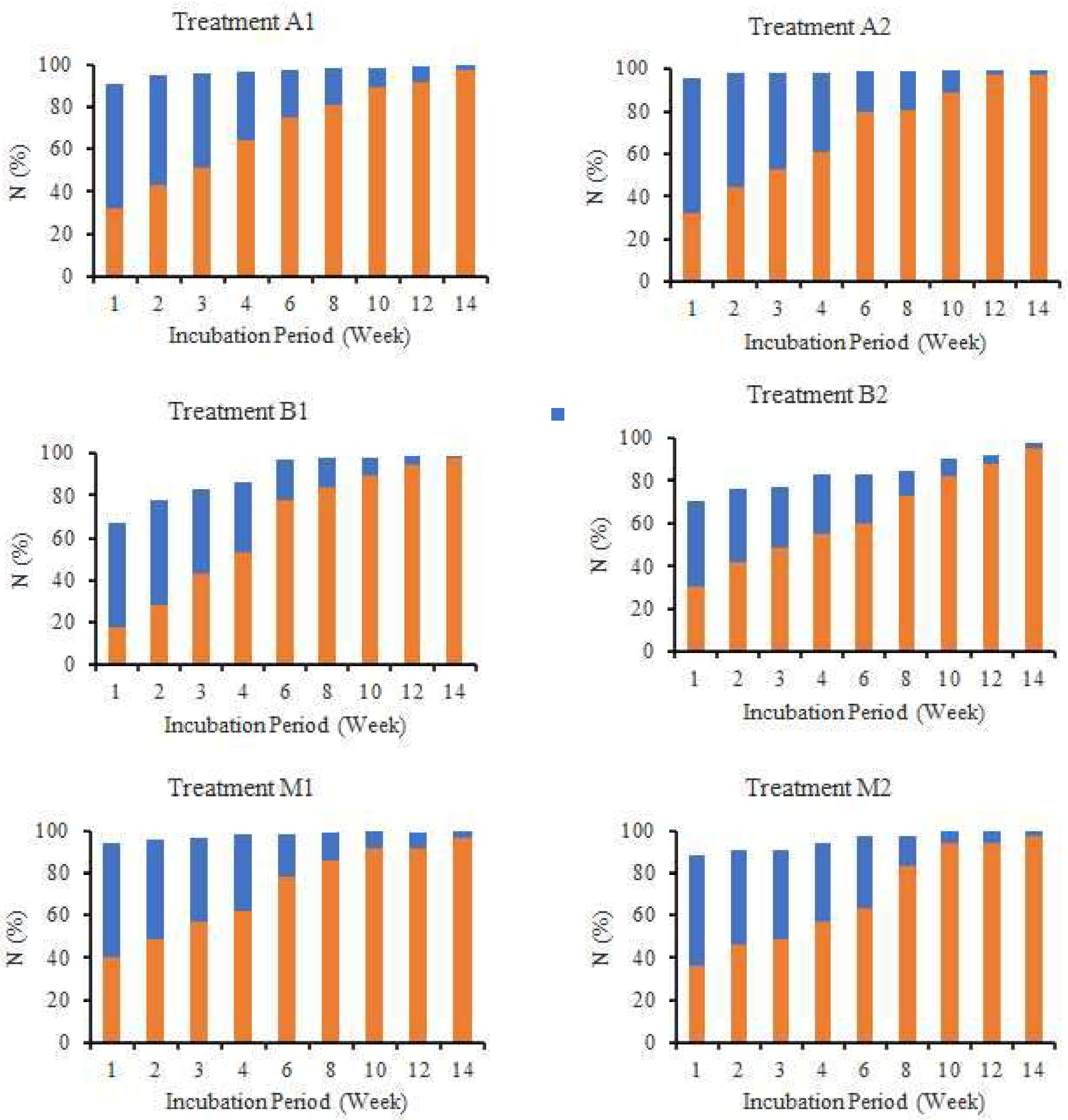

Figure 5. Diagram showing nitrogen (%) in the soil on the tested CRFs over 14 weeks of incubation. ■: N0, ■: NH_4.

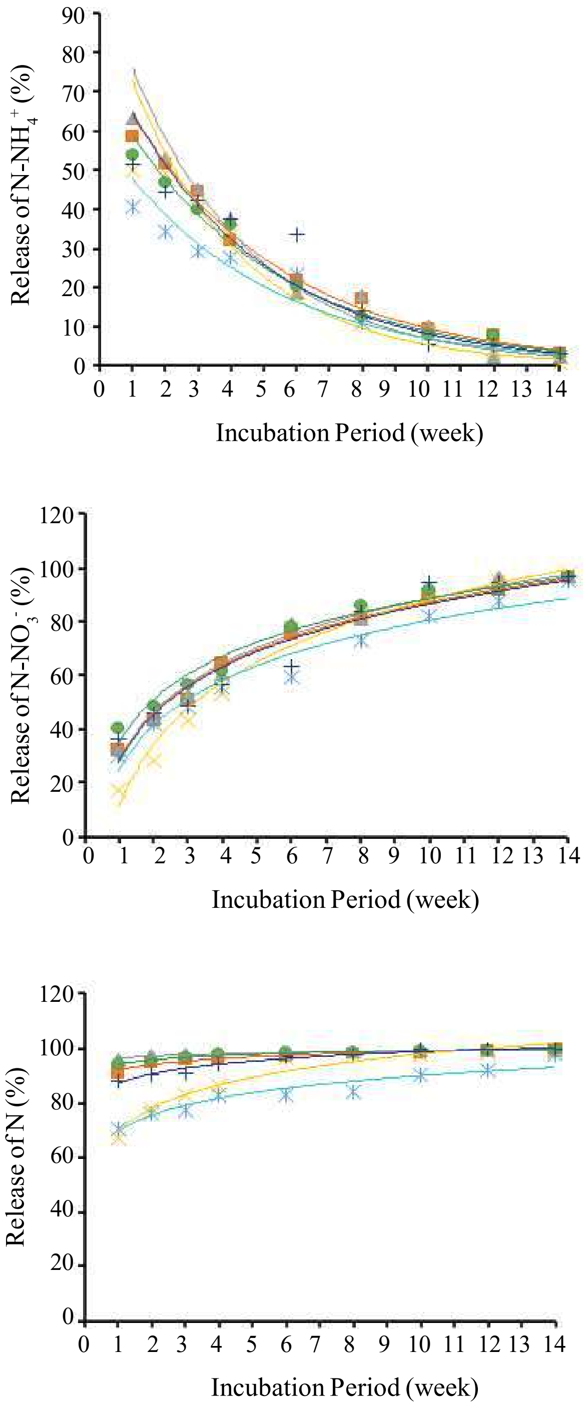

Figure 6. Potassium release (%) into the soil from the six fertilizer treatments over 14 weeks incubation. ―■―: A1, ―▲―: A2, ―✳―: B1, ―✳―: B2, ―●―: M1,+ : M2.

Nitrogen release in this study can be illustrated by comparing percentage levels of NH_4-N and NO_3-N. As shown in Figure 5, in the 1st week incubation, CRF yielded a slower nitrogen release rate than Mutiara NPK (16-16-16). It was because CRF fertilizer contained zeolite, which can increase nitrogen fertilizer availability (duration). Zeolite in CRF can adsorb NH_4-N in its framework. The addition of zeolite in N fertilizer causes N in the soil can available longer. In contrast, fertilizers that do not add zeolite will cause N immediately turn into nitrate and leach by running off the surface (Suwardi, 2002). A similar finding was reported by Jakkula and Wani (2018), that is, zeolite reduces the volatilization of ammonium nitrogen and leaching of nitrate nitrogen, ultimately helping to bring about rising crop yields.

The CRF used in this study was a formulation of NPK compound fertilizer made from urea, DAP (diammonium phosphate), KCl (potassium chloride), and mineral zeolite as an additive. Based on the data above, CRF 30-6-8 produced the lowest nitrogen release from ammonium and nitrogen nitrate. In contrast, the highest release rate occurred in the case of potassium.

Potassium Release

The outcomes of the potassium release from the six fertilizer treatments over the 14-week incubation period are illustrated in Figure 6. As incubation time elapsed, the potassium release gradually increased until the 14th week. In the first week, 20-30% K was released, rising to 30 – 70% by 14th week. Potassium release in B1 and B2 treatments was faster (31-32%) than in the other treatment combinations (A1, A2, M1, and M2), which ranged from 22 to 28%. Initial K release from CRF at a dose of 1200 kg ha^{-1} came out higher than from CRF at 600 kg ha^{-1}. At the 8th incubation week, both CRF B (30-6-8) and CRF A (16-16-16) showed a lower potassium release at a dose of 1200 kg ha^{-1} compared to a dose of 600 kg ha^{-1}. In contrast, potassium release in Mutiara NPK remained high at a dose of 1200 kg ha^{-1}.

CONCLUSIONS

NH_4-N in the soil tends to be released at a declining rate over time. On the other hand, NO_3-N and potassium are lost from the soil at a rate that increases with time. In this study, 40 – 60% of the NH_4-N was initially released and gradually declined to almost 0% after the 14th incubation week. In contrast, 17 – 40% of the NO_3-N was initially lost, then steadily increased, peaking at 100% by Week 14. In the case of potassium, the early release rate ranged from 20 to 30%, rising to 30 – 70% at the 14th incubation week. The standard deviation (SD) values indicated that NH_4^+ SD values decreased as the weeks progressed, while NO_3^- SD values were higher than NH_4^+ SD values, indicating more significant variability in NO_3^- values.

Meanwhile, potassium SD values were high for most weeks and treatments, indicating significant variability in potassium release values. In general, nitrogen values were relatively consistent across treatments and weeks. The treatment of B2 (CRF B), at a dose of 1200 kg/ha, showed the slowest rate of nitrogen release, while all treatments slightly affected potassium release.

REFERENCES

Abatenh E, B Gizaw, Z Tsegaye and G Tefera. 2018. Microbial function on climate change - a review. *Environ Pollut Climate Change* 2: 147. doi: 10.4172/2573-458X.1000147.

Agustina TE, I Rizky, MEW Utama and MI Amal. 2018. Characterization and utilization of zeolite for NPK slow-release fertilizer. *Int J Eng* 31: 622-628.

Beig B, MBK Niazi, Z Jahan, A Hussain, MH Zia and MT Mehran. 2020. Coating materials for slow release of nitrogen from urea fertilizer: a review. *J Plant Nutrition* 43: 1510-1533.

Chen J, X Fan, L Zhang, X Chen, S Sun and R-Cang Sun. 2020. Research progress in lignin-based slow/controlled release fertilizer. *ChemSusChem* 13: 4356-4366. doi: 10.1002/cssc.202000455.

Daza MC, J Diaz, E Aguirre and N Urrutia. 2015. Effect of slow-release fertilizers on nitrate leaching and nitrogen nutrition in stevia. *Rev Colomb Cienc Horticolas* 9: 112-123. doi http://dx.doi.org/10.17584/rcch.2015v9i1.3750.

Evi MD, Suwardi, DT Suryaningtyas and S Anwar. 2017. Utilization of natural zeolites as Cu (Ii) and Zn (Ii) adsorbent. *J Trop Soils* 21: 153-60.

El-Beltagi HS, MR Sofy, MI Aldaej and HI Mohamed. 2020. Silicon alleviates copper toxicity in flax plants by up-regulating antioxidant defense and secondary metabolites and decreasing oxidative damage. *Sustainability* 12: 4732. doi https://doi.org/10.3390/su12114732.

El-Nahas S, HM Salman, and WA Seleeme. 2019. Aluminum building scrap wire, take-out food containers, potato peels, and bagasse as valueless waste materials for nitrate removal from water supplies. *Chemistry Africa* 2: 143–162.

Gu J and J Yang. 2022. Nitrogen (N) transformation in paddy rice field: its effect on n uptake and relation to improved N management. *Crop Environ* 1: 7-14.

Hasanuzzaman M, MHM Borhannuddin Bhuyan, K Nahar, Md Shahadat Hossain, J Al Mahmud, Md Shahadat Hossen, AA Chowdhury Masud, Moumita and M Fujita. 2018. Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy* 8: 31. doi https://doi.org/10.3390/agronomy8030031.

Hidayatussittah N. 2018. Pola pelepasan ammonium, nitrat, dan kalium dari slow release fertilizer (SRF) pada Epiaquept. [skripsi]. Institut Pertanian Bogor, Bogor. (in Indonesian).

Hou W, X Xue, X Li, MR Khan, J Yan, T Ren, R Cong and J Lu. 2019. Interactive effects of nitrogen and potassium on grain yield, nitrogen uptake and nitrogen use efficiency of rice in low potassium fertility soil in China. *Field Crop Res* 236: 14-23.

Jakkula VS and SP Wani. 2018. Zeolites: potential soil amendments for improving nutrient and water use efficiency and agriculture productivity. *Sci Revs Chem Commun* 8: 119.

Krapp A. 2015. Plant nitrogen assimilation and its regulation: a complex puzzle with missing pieces. *Curr Opin Plant Biol* 25: 115–122.

Li S-Xiu, Z-Hui Wang, and BA Stewart. 2013. Chapter Five - responses of crop plants to ammonium and Nitrate N. In DL Sparks (ed). *Advances in agronomy*. Department of Plant and Soil Sciences, University of Delaware, Newark, Delaware, USA, pp. 115–122.

Nainggolan GD. 2010. Pola pelepasan nitrogen dari pupuk tersedia lambat (*slow release fertilizer*) urea-zeolit-asam humat. [Skripsi]. Institut Pertanian Bogor, Bogor. (in Indonesian)

Sardans J and J Peñuelas. 2015. Potassium: A neglected nutrient in global change. *Global Ecol Biogeogr* 24: 261-275.

Soltys L, I Myronyuk, T Tatarchuk and V Tsinurchyn. 2020. Zeolite-based composites as slow-release fertilizer. *Physics and Chemistry of Solid State* 21: 89-104.

Suryaningtyas DT, YGN Fatiha, P Oktariani and Suwardi. 2023. Zeoponic, a plant growing medium from zeolite mineral. *IOP Conference Series: Earth and Environmental Science* 1133: 012020. doi: 10.1088/1755-1315/1133/1/012020.

Suwardi. 2002. Prospek pemanfaatan mineral zeolit di bidang pertanian. *J Zeolit Indonesia* 1:5-12.

Suwardi. 2004. Pengaruh penambahan zeolit pada media tumbuh tanaman pada tanaman melon dan semangka dalam sistem hidroponik. *J Zeolit Indonesia* 3:30-36.

Suwardi. 2007. Deposit dan sifat-sifat mineral zeolit serta pemanfaatannya sebagai bahan pembenah tanah. *Prosiding Seminar Nasional Himpunan Ilmu Tanah Indonesia*, Yogyakarta, pp. 248-257.

Suwardi and H Wijaya. 2013. Peningkatan produksi tanaman pangan dengan bahan aktif asam humat dengan zeolit sebagai pembawa. *J Ilmu Pertanian Indonesia* 18: 79-84.

Tian X-Fei, C-Liang Li, M Zhang, Y-Yan Lu, Y-Le Guo and L-Fei Liu. 2017. Effects of controlled-release potassium fertilizer on available potassium, photosynthetic performance, and yield of cotton. *J Plant Nutrition and Soil Science* 180: 505-515.

Xu X, X Du, F Wang, J Sha, Q Chen, G Tian, Z Zhu, S Ge and Y Jiang. 2020. Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Front Plant Sci* 11: 904.

Zulfiqar F, M Navarro, M Ashraf, NA Akram, S Munne'-Bosch. 2019. Nano fertilizer use for sustainable agriculture: advantages and limitations. *Plant Sci* 289: 110270.