Release pattern of ammonium, nitrate, and potassium from Slow-Release Fertilizer (SRF) in the Soil

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Abstract

The low efficiency of nitrogen and potassium fertilization is one of the pressing problems in tropical agriculture. This is because the humid tropical climate, like what Indonesia has, which is characterized by high rainfall, causes a high rate of leaching of nitrogen and potassium in the soil. To improve fertilization efficiency, one practical option is to find a method of slowing down the release of available nutrients in the soil. Thus, the purpose of this study was to evaluate the pattern and rate of the release of nitrogen (in the form of ammonium and nitrate) and potassium from slow-release fertilizer (SRF). This study used three types of fertilizers, namely: SRF (13-8-10), SRF (19-12-15) and Mutiara granule fertilizer (16-16-16). Treatment dosages used corresponded to 600 kg/ha and 1200 kg/ha, with three replications, and observed over a 10-week incubation period. The results showed that ammonium release from SRF fertilizer in the first week that ranged 28.94% - 41.45%, then decreased progressively with incubation time, while that of nitrate ranged 5.77 - 7.21%, but increased over time. On the other hand, the potassium from SRF fertilizer was released by rates of 9.56% - 24.58% during the first week, increasing with incubation time. The same pattern of nutrient release was observed in the case of Mutiara fertilizer, however at much greater rates compared to SRF, viz.: for ammonium (44.56 - 46.91%, at decreasing rate afterwards with incubation time), nitrate (26.33 - 30.10%, at increasing rates afterwards), as well as for potassium (15.39 - 15.75%, at increasing rates afterwards). In summary, the SRF (13-8-10), applied at a dosage corresponding to 1200 kg/ha yielded the slowest rate of nutrient release in the soil.
1. Introduction

Nitrogen is one of the most limiting factors in crop production, be it in the tropics or in the temperate regions. It is needed in relatively large quantities by plants, but its presence in the soil is always limited by its source and availability in nature. Nitrogen in the air, in the form of N\textsubscript{2} gas, occupies 78% of the volume of the atmosphere. It can be absorbed by plants in the form of ammonium or nitrate. However, nitrogen is not abundant in acidic soils [2], and, in raw form, it cannot be used by plants. Nitrogen gas must first be converted into a form of ammonium or nitrate, through the process of ammonification and nitrification, respectively, so that it can be used by plants. In fertilization, the nutrient N is usually given in the form of urea or ZA.

Similarly, potassium is a macro-nutrient that also plays an important role in plant growth and production. According to [5], potassium is the mineral nutrient that is most needed by plants after nitrogen. The total potassium present in the soil varies with the type of host rock and geographical location, but, in general, it is estimated to be between 0.5 and 2.5% [1]. However, around 90 - 98% of total potassium in the soil is in a form that is not available, meaning, it cannot be absorbed by plants [8]. Low absorption by plants of available potassium in the soil impacts on their growth, resulting in low-quality crop yields [4]. The amount of potassium absorbed by plants varies from 50 to 200 kg / ha, depending on the plant species and the desired level of production.

On the other hand, zeolites are microporous minerals with high cation exchange capacity (CEC), hence, they are very useful as adsorbers, binders, and cation exchangers. Its high CEC allows greater number of lattice exchanges, so that more ions can be adsorbed by the lattice. The adsorption of soil nutrient ions in the zeolite cavity / lattice is only temporary, and the nutrients are made available to plants only when needed [12]. Given their high exchange properties, zeolites can temporarily bind and store nutrients in the soil, and then release them back into the soil when plants need them. This is particularly true for N, because of the high zeolite adsorption selectivity to ammonium ions. Further, by adsorbing ammonium, zeolites inhibit the conversion of ammonium into nitrate, so that the loss of N in the form of nitrates, that is easily washed out by rainwater, is regulated. If the N level in the soil solution is decreased, the N adsorbed by zeolite would be released slowly for plant use [11].

In this context, the use of fertilizers that contain zeolite and humic acid is expected to increase the efficiency of nitrogen and potassium fertilization. The fertilizer can be prepared in pill form with a parabolic granulation device.

2. Materials and Methods

2.1 Preparation

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, Bogor Agricultural University (IPB). Collected soil samples were incubated and stored at the Physical Resources Development Laboratory, while soil chemical analysis was carried out at the Soil Chemical and Fertility Laboratory. Dramaga Inceptisol soil, which is characterized by a rather thick solum (1-2 meters); black, or gray to dark brown; texture of dust, dusty clay or clay; crumb soil structure; loose consistency; pH 5.00 - 7.00; and high organic matter content of 10% -30% (Soepardi 1983), was used. Based on the analysis criteria for soil chemical properties (PPT 1983), the Dramaga Inceptisol
soil has a moderate total N-content, but its K-available content is low, according to the initial analysis.

The tools used in the field included hoe, sack and spill to dry the soil, and a sieve to sift the soil; while the tools used for analysis in the laboratory were pH meter, EC meter, flame photometer, soil oven, weigh bottles, weights, shake bottles, shaking machine, 250-ml Erlenmeyer flask, plastic tube, filter paper, test tube, 100-ml centrifuge tube, glass stirrer, pipette, boiling flask, analytical balance, 50-ml measuring flask, 100-ml measuring flask, distillation apparatus, distillation flask, and digital burette.

2.2 Incubation

Two types of slow-release fertilizers (SRF), with different NPK compositions (13-8-10 and 19-12-15), were tried in this study. In addition, Mutiara NPK (16-16-16) was used as a comparison fertilizer. Soil composites were collected at a depth of 0-20 cm, and then dried. For analysis of the chemical properties in the laboratory, the soil sample was ground and sieved on a 2-mm sieve. The measurement of the rate of fertilizer release was carried out by the incubation method, in an open space in the laboratory. Air-dried soil, weighing 129.77 g, or equivalent to 100 g absolute dry weight (ADW) with 11.96% ground water content, was inserted into a cylindrical tube-shaped plastic container (the incubation jar shown in Figure 1), with a diameter of 6.00 cm and a height of 6.70 cm. The SRF and Mutiara NPK fertilizer were weighed and then applied into the soil. Water was added to the fertilizers until field capacity (48.29%) moisture content was reached. Finally, the incubation jar was covered with a protective polyethylene plastic sheet. For this study, two fertilizer dosage levels, corresponding to 600 kg/ha (A) and 1200 kg/ha (B), were tried, and each treatment was replicated three times. The material composition of the two SRF fertilizers are summarized in Tables 1 and 2 below.

![Figure 1. Illustration of incubation jar containing soil and fertilizer for incubation over 10 weeks](image-url)
Incubation was carried out at room temperature in the incubator for 10 weeks. Observations and measurements on ammonium, nitrate, nitrogen, potassium, pH, EC and soil water content were undertaken weekly. The study data were used in the subsequent statistical and regression analyses.

Table 1. SRF 13-8-10 nutrient content

| Materials | Amount (mg) | % Nutrient |
|-----------|-------------|------------|
| Urea      | 119.45      | 13.00      |
| DAP       | 173.91      | 8.00       |
| KCl       | 166.67      | 10.00      |
| ZA        | 208.33      | 5.00       |
| MgSO₄     | 25.00       | 2.00       |
| ZnO       | 4.44        | 0.40       |
| CuO       | 3.33        | 0.30       |
| MnSO₄     | 3.75        | 0.30       |
| CaCO₃     | 72.73       | 4.00       |
| Zeolite 11| 222.38      |            |
| **Total** | **1000.00** |            |

Table 2. SRF 19-12-15 nutrient content

| Materials | Amount (mg) | % Nutrient |
|-----------|-------------|------------|
| Urea      | 234.88      | 19.00      |
| DAP       | 260.87      | 12.00      |
| KCl       | 250.00      | 15.00      |
| ZA        | 166.67      | 4.00       |
| ZnO       | 4.44        | 0.40       |
| CuO       | 3.33        | 0.30       |
| MnSO₄     | 3.75        | 0.30       |
| Zeolite 12| 76.06       |            |
| **Total** | **1000.00** |            |

2.3 Soil Analysis
At the laboratory, a soil sample was taken for analysis from each incubation jar for each treatment (including control). The remaining fertilizer was removed from the incubation jar, and the soil in the middle of the incubation jar, that was not directly in touch with the fertilizer, was stirred and taken for analysis. The amount of soil taken was 10 grams for N-available analysis, 10 grams for pH and EC measurement, and 1.5 grams for K-available analysis. Using the same soil sample, pH and EC was determined using a calibrated pH meter and EC meter. Available N (in the form of ammonium and nitrate) was determined by the Distillation method. In this method, 0.1N HCl, 1N KCl, 40% NaOH, 4% boric acid, Conway indicator, devarda alloy, and distilled water were used.
On the other hand, K-available was determined by the Bray-1 method with a flamephotometer measuring instrument, at a wavelength of 660 micrometers. The analysis of N-available K-available was calibrated by reducing the nutrient content in the soil without fertilizer every week (control).

2.4 Data Analysis and Interpretation

The rate of nutrient release from fertilizer can be determined by using a number of kinetic models, including zero-order kinetics, first-order kinetics, and Elovich models. The zero-order kinetics model is expressed using the following equations:

\[ \text{Co} - \text{Ct} = k_0 \cdot t \] .............................. (1)

the integration form of Equation (1) is:

\[ \text{Ct} = \text{Co} - k_0 \cdot t \] .............................. (2)

where \( \text{Ct} \) is the nutrient concentration in the soil at time \( t \), \( \text{Co} \) is the initial concentration of fertilizer applied, \( k_0 \) is the zero-order rate with a unit of concentration per unit time. By plotting \( \text{Ct} \) against \( t \), zero-order kinetics is obtained.

The first-order kinetics model is expressed by equations

\[ \frac{d\text{Ct}}{dt} = -k_1 \cdot \text{C} \] .............................. (3)

The integration form of Equation (3) is

\[ \ln \text{Ct} = \ln \text{Co} - k_1 \cdot t \] .............................. (4)

where \( \text{Ct} \) is the concentration of nutrients in the soil at time \( t \), \( k_1 \) is a first-order rate constant in units per unit time. By plotting \( \ln (\text{Ct}) \) against \( t \), a first-order kinetics is obtained.

The Elovich model is expressed by equations (Chien and Clayton, 1980)

\[ \frac{d\text{Ct}}{dt} = a \cdot \exp (-bq_1) \] .............................. (5)

The integration form of Equation (5) is

\[ \text{Ct} = \frac{1}{b} ( \ln(ab) + \frac{1}{b} \ln t ) \] .............................. (6)

where \( \text{Ct} \) is the amount of nutrients in the soil at time \( t \), where \( a \) and \( b \) are constants. By plotting \( \text{Ct} \) with \( \ln t \), we get constants \( a \) and \( b \).

For each treatment, average values for all observations were obtained, corrected with the respective control, and range values (lowest to highest percentages for each week) were generated. The sets of average values for each Treatment over the 10-week incubation period were used to construct the prediction graphs, using the Microsoft Excel 2013 application. The resulting graphs (Figures 2, 3, and 4) display the pattern in the rates (percentage) of cumulative values of released ammonium, nitrate, and potassium, respectively. The percentage values for each nutrient were
obtained from the ppm values (mg / kg), which were first converted to mg /100g, and then multiplied by the maximum level of fertilizer in mg.

3. Results and Discussions
3.1 Ammonium release pattern

Figure 2. Ammonium release pattern for SRF and Non-SRF fertilizers

Figure 2 above shows the pattern of the release of ammonium from the soil samples applied with fertilizers, namely: SRF (13-8-10), SRF (19-12-15), and Mutiara fertilizer (16-16-16), each of which was applied in two treatments dosages - corresponding to 600 kg/ha (A) and 1200 kg/ha (B). The lowest ammonium release percentage from the first week to the 10th week was exhibited by Treatment SRF (13-8-10) B, with release rate 28.94% during the first week, and 1.54% in the 10th week. Following closely was Treatment SRF (13-8-10) A, with release rate 40.38% during the first week, and 2.24% in the 10th week. A similar trend was shown by Treatment SRF (19-12-15), both Treatment B and Treatment A, in that order. Treatment SRF (19-12-15) B, had a release rate 41.45% during the first week, and 2.85% in the 10th week, followed by Treatment SRF (19-12-15) A, with release rate 35.53% during the first week, and 1.97% in the 10th week. These results are consistent with the findings of [3], who found that the release rate of ammonium decreased progressively every incubation week to near zero with the use of SRF fertilizer mixed with urea, zeolites, and humic acid. The same trend of ammonium release was observed in the case of Mutiara fertilizer, however at much greater rates compared to SRF, viz.: for ammonium (44.56 - 46.91% during the 1st week, and 4.47% - 5.81% in the 10th week). The above data implies that SRF fertilizer can slow down the release of ammonium, as compared to Mutiara NPK (16-16-16) fertilizer. The ability of the SRF fertilizer to regulate the release of ammonium is likely brought about by their zeolite content (as shown in Tables 1 and 2). Zeolite has the natural ability to absorb NH4+ ions; the exchange grating in the zeolite binds the hydrolyzed NH4+, so the ion can readily be adsorbed...
by the zeolite. It is detached from the zeolite only when the concentration equilibrium in the soil substance is lower than the concentration equilibrium in the fertilizer [10].

3.2 Nitrate release pattern

Figure 3 shows an increase in the rate of nitrate release from the first to the 10th week, which was the opposite pattern in the ammonium release. Nitrate release in the first week ranged from 5-30% and increased to as much as 100% in the 10th week. The lowest nitrate release was exhibited by the SRF (13-8-10) B treatment, at 5.92% in the first week and reaching 77.05% in the 10th week. A similar trend was shown by Treatment SRF (19-12-15), both Treatment B and Treatment A, in that order. Treatment SRF (19-12-15) B, had a nitrate release rate 6.80% during the first week, and 83.84% in the 10th week, followed by Treatment SRF (19-12-15) A, with nitrate release rate 7.21% during the first week, and 79.49% in the 10th week. In comparison, Mutiara treatment had the highest nitrate release percentage range of 26.33% - 30.10% in the first week and 91.46 - 94.17% in the 10th week.

3.3 Potassium release pattern

In Figure 4 below, the release rate of potassium in the SRF fertilizer shows an increasing trend every week, reaching a range of 42.08% - 57.75% in the 10th week. This is likely because the zeolite that was added to SRF bound the very small K+, and since zeolite minerals possess a high selectivity in absorbing K+ cations [6], then K+ is adsorbed by the zeolite. The pattern of potassium release in the Mutiara fertilizer likewise showed a weekly increase, but Mutiara fertilizer released potassium only at a rate of 30.08% to 39.19% in the 10th week. This is due to the fact that Mutiara fertilizers do not contain zeolites, unlike the SRF fertilizers. As stated earlier, SRF fertilizers have high-CEC zeolites, and high CEC can affect the availability of potassium in the soil.
Table 3 below shows the linearized (1st-order) regression equations for each fertilizer Treatment unit, all of which produced highly reliable prediction estimates, based on the high values of the linear regression coefficients ($r^2$). It can be observed that the coefficients of the variable $x$, denoting the slope of each graph, also represent the coefficients ($k$) that express the respective rates of release of ammonium, nitrate, and potassium from the soil for the different treatment units in this study. As demonstrated by the prediction equations, the coefficient value (0.015) for SRF (13-8-10) B is the lowest among the ammonium regression equations, implying that this Treatment (SRF (13-8-10) B) produces the slowest rate of ammonium release. This can be explained by the fact that this SRF contained a much higher amount of zeolite. A similar result can be seen in nitrate release rate, with the lowest value of coefficient (0.0693), again for the same reason. However, a different result can be observed in the case of potassium release, in which the lowest coefficient value (-0.0327) occurs also in Treatment SRF (13-8-10) B but with a negative sign, meaning the release of potassium is increasing but at a decreasing rate over the 10-week observation period.

Table 3. Predicted patterns in the rate of release of ammonium, nitrate, and potassium

| Treatment          | Ammonium Equations | Ammonium $r^2$ | Nitrate Equations | Nitrate $r^2$ | Potassium Equations | Potassium $r^2$ |
|--------------------|--------------------|---------------|------------------|---------------|---------------------|-----------------|
| SRF (13-8-10) A    | $y = 0.0209x + 1.711$ | 0.7121        | $y = -0.0697x + 1.9224$ | 0.9886        | $y = -0.0124x + 1.6454$ | 0.804           |
| SRF (13-8-10) B    | $y = 0.015x + 2.0615$ | 0.7704        | $y = -0.0693x + 2.263$ | 0.9867        | $y = -0.0327x + 2.0279$ | 0.9774          |
| SRF (19-12-15) A   | $y = 0.0186x + 1.8881$ | 0.7481        | $y = -0.0762x + 2.0956$ | 0.973         | $y = -0.0257x + 1.9619$ | 0.9573          |
4. Conclusion

Slow-release fertilizer (SRF) can significantly restrict the release of nitrogen (in the form of ammonium and nitrate) and potassium in the soil, that would otherwise be washed away by rainwater, hence, made unavailable to plants and simply wasted away. This is mainly due to the presence of high-CEC zeolite that can bind, adsorb, and keep the mineral nutrients over a period of time, releasing the adsorbed nutrients only when needed by plant roots. This natural nutrient release mechanism in the soil is governed by the balance in the nutrient concentration equilibrium in the zeolite with the nutrient concentration equilibrium in the soil. The rate of ammonium release in the SRF-fertilized soil goes down progressively over time, while that of nitrate increases over time. Potassium release from SRF-fertilized soil likewise goes up, but at a decreasing trend over time. In summary, the SRF (13-8-10) fertilizer, applied at a dosage corresponding to 1200 kg/ha, yields the best results in terms of regulating nutrient release rates in the soil.

5. References

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