Effect of organic fertilizer on kinetics of potassium release and rice uptake in inceptisols Kalitirto, Sleman

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Abstract. This study aims to determine the effect of organic fertilizer on kinetics of potassium release and uptake and to find the best kinetic models describing K release from soils. The treatments included control, inorganic fertilizer, 10 ton/ha cow manure, 5 ton·ha⁻¹ green manure, and 7.5 ton·ha⁻¹ cow + green manure (2:1). The experiment was analyzed using RCBD with three replications. The kinetics of non-exchangeable K release was extracted with 0.01 M CaCl₂ for 2 to 168 h and data of K release were fitted to five mathematical models: zero-order reaction, first-order reaction, power function equation, parabolic diffusion and Elovich equation. The results showed that plant and root-K uptake from control, inorganic fertilizer, cow manure, green manure and cow + green manure were respectively 45.16; 62.33; 61.46; 55.66; 68.89 mg/clump and 15.63; 23.09; 44.91; 17.53; 23.41 mg/clump. The treatments were not significant on plant uptake, root uptake and K release so organic fertilizer can be used to replace inorganic fertilizer application. Among the five equations, power function best described the K release pattern with R-square was 0.50. The constant b, an index of K release rate, ranged from 0.003 to 0.018 ppm·h⁻¹ in the power function model.

1. Introduction
Volcanic ash from Merapi Mountain contains feldspars and pyroxene minerals as reserves of soil nutrients [1]. Feldspars mineral weathering produces several types of clay minerals such as halloysite[2], allophan[3], kaolinite [4, 5] and smectite[6]. There are four forms of potassium in soil: dissolved potassium, exchangeable potassium, non-exchangeable potassium and unavailable potassium. The presence of potassium is very dynamic and involves a reaction of equilibrium between different potassium forms [7]. Non exchangeable potassium from reserves makes an important contribution to plant potassium supply [8].

For optimal nutrition of crop, the replenishment of a potassium depleted soil solution is affected predominantly by the release of non-exchangeable potassium [9]. Soil solution and exchangeable potassium need to be replenished continually with potassium through the release of non-exchangeable potassium through the weathering of potassium reserves or the addition of potassium fertilizers [10]. In the absence of potassium input from the outside, rice growth depends only on the potential availability of native potassium and rate of potassium release from non-exchangeable potassium to soil solution.

Organic and inorganic amendment influence release distribution dynamics and potassium fixation. Vermicompost increases the cumulative release of potassium [11] and an oxalic acid solution with low pH is able to release more potassium from weathered minerals and alkaline soil. Oxalic acid decrease the soil potassium adsorption and increase the soil potassium desorption [12]. Therefore, the objectives of the present study were (i) to determine the effect of organic fertilizer on kinetics of
potassium release and rice uptake and (ii) to find the best kinetic models to describe K release from soils.

2. Materials and Methods
The experiment was divided by three steps and was held in PusatInovasi Agro Teknologi (PIAT) Berbah, Sleman. The incubation experiment and K release analysis and last step (soil, organic fertilizer and tissue analysis) were held in Soil Science Laboratory and Chemistry and Soil Fertility Laboratory, Agriculture Faculty, Universitas Gadjah Mada, Yogyakarta.

The field experiment was analyzed using randomized complete block design (RCBD) with three replications. Treatments consisted of type organic fertilizer, included i) control; ii) NPK fertilizer (150 kg·ha⁻¹ urea, 150 kg·ha⁻¹ SP 36 and 70 kg·ha⁻¹ KCl); iii) 10 ton·ha⁻¹ cow manure, (iv) 5 ton·ha⁻¹ green manure (Tithoniadiversifolia and residual biomass harvest of Arachishypogaea), and (v) 7.5 ton·ha⁻¹ cow manure + green manure (cow manure and residual biomass harvest of Arachishypogaea L. 2:1).

Potassium release kinetics experiments were analyzed in the laboratory using soil samples after harvest. About 2 g of 2 mm sieved soil sample was treated with 20 mL of CaCl₂ solution in a 50 mL centrifuge tube. The soil suspension was equilibrated for 2; 4; 6; 24; 48; 96; 120; 144 and 168 h at 25±1°C. After addition of CaCl₂ solution, the soil suspension was shaken in a rotary shaker for 15 min (200 rpm) and later centrifuged at 4000 rpm. Potassium content in the supernatant solution were determined by flame photometer [13, 14].

The K release data obtained from the analysis of potassium content from the extracts were tested for the mathematical fit to different kinetic equation namely,

- Power function equation: ln q = ln a + b ln t
- Parabolic diffusion: q = a + b t¹/²
- First-order reaction: ln (q₀ - q₂) = -a t
- Elovich equation: q = a + b ln t
- Zero-order reaction: q₂ = a - b t

Where, q₂ is the cumulative potassium released (mg·kg⁻¹) at time t (h), q₀ is the maximum cumulative K released mg·kg⁻¹ and a and b are constants. Five models were tested by the least square regression analysis to determine which equation describe the non exchangeable K release in a better manner. All data is analyzed to know the effect of treatments on parameters. Regression analysis is carried out using the SAS 9.1 software.

3. Results and Discussion
Based on table 1, the soil pH was still in neutral value (6.93). In general, optimum nutrient availability and absorption was under neutral pH conditions. Soil organic C content was low (1.3%). Soil organic matter derived from the remains of microorganism, or decayed plants and animals over a period of time[15]. The role of organic matter on the availability of nutrients in the soil was related to the process of mineralization[16]. Therefore, soil with low organic matter content need input organic matter from outside.

Total nitrogen content consist of inorganic and organic nitrogen [17]. Total N was moderate (0.24%) and it was expected to be able to support the growth of rice. The content of P₂O₅ extracted with Olsen and content of available Mg were very low, 2.67 ppm and 0.37 cmol(+)·kg⁻¹, respectively. The content of available K was low (0.62 cmol (+)·kg⁻¹) while the content of available Ca was high (16.46 cmol (+)·kg⁻¹). The availability of phosphorus was generally low in acid and alkaline soils [18]. On soils with pH above 7, phosphorus was bound by Mg and Ca. This was evidenced by the result of analysis of high soil available Ca. Some nutrient content in the soil were low, so to improve the ability of soil to support the growth of rice need nutrient input from outside, including giving of inorganic and organic fertilizer.
Table 1. Some chemical properties of the studies soils.

| Parameters       | Units | Value | Level*       |
|------------------|-------|-------|--------------|
| pH H₂O           |       | 6.93  | Netral       |
| Organic carbon   | %     | 1.3   | Low          |
| Total nitrogen   | %     | 0.24  | Moderate     |
| P₂O₅ Olsen       | ppm   | 2.67  | Very low     |
| Available K      | cmol(+)-kg⁻¹ | 0.62 | High        |
| Available Ca     | cmol(+)-kg⁻¹ | 16.46 | High        |
| Available Mg     | cmol(+)-kg⁻¹ | 0.37 | Low          |

* BalaiPenelitian Tanah (2005)

Carbon content of *Arachishypogaea* L. and *Tithoniadiversifolia* were high (43.90% and 41.25%, respectively) compared to cow manure (25.96%). Structure of plant cell consist of cellulose, hemicelluloses and lignin that composed from carbon [19]. The highest total nitrogen content was found in *Tithoniadiversifolia* (4.13%). The content of total nitrogen of *Arachishypogaea* L. and cow manure were 2.37% and 1.40%, respectively. [20] reported that *Tithoniadiversifolia* was one of the potential green manure as a source of nitrogen and phosphorus. C/N ratio of cow manure, *Arachishypogaea* L. and *Tithoniadiversifolia* were low (18.60; 18.53 and 9.98, respectively) and ready application to soil.

Table 2. Chemical properties of organic fertilizer.

| Chemical properties | Cow manure | *Arachishypogaea*L. | *Tithoniadiversifolia* |
|---------------------|------------|---------------------|------------------------|
| Organic carbon*     | (%)        | 25.96⁹         | 43.90⁹                | 41.25⁹                  |
| Total N**           | (%)        | 1.40¹           | 2.37⁹                 | 4.13¹                   |
| C/N ratio***        |            | 18.60           | 18.53                 | 9.98                    |
| Total P**           | (%)        | 1.94⁹           | 0.65¹                 | 0.82¹                   |
| Total K**           | (%)        | 1.27¹           | 2.55¹                 | 2.80¹                   |
| Total Ca**          | (%)        | 1.74⁹           | 1.56¹                 | 1.99¹                   |
| Total Mg**          | (%)        | 0.07⁹vl         | 0.06⁹vl               | 0.06⁹vl                 |

vl= very low, l= low, m= moderate and h= high
* SNI 19-7030-2004
** Bolan et al., 1980
*** Balittan, 2005

Total phosphorus and total potassium content of cow manure, *Arachishypogaea*L. and *Tithoniadiversifolia* were respectively 1.94 %; 0.65 %; 0.82% and 1.27 %; 2.55 %; 2.80%. These three fertilizer materials had high potassium levels so it was highly recommended as a potassium-rich organic fertilizer. Total calcium and magnesium content were respectively 1.74 %; 1.56 %; 1.99 % and 0.07 %; 0.06 %; 0.06 %. Organic fertilizer contain various nutrients, both macro and micro nutrients and also had levels vary widely. Other benefits of organic fertilizer were in terms of soil biology and soil physics so that organic fertilizers can also be called as a good soil conditioner.

Table 3. Effect of fertilizer application on potassium concentration and potassium uptake.

| Treatments        | Available K (cmol·kg⁻¹) | K root (%) | K plant (%) | K root uptake (mg/clump) | K plant uptake (mg/clump) |
|-------------------|-------------------------|------------|-------------|--------------------------|---------------------------|
| Control           | 0.70ᵃ                    | 0.53ᵇ      | 1.34ᵃ       | 15.63ᵇ                   | 45.16ᵇ                    |
| Inorganic         | 0.64ᵃ                    | 0.69ᵇᵇ     | 1.44ᵃ       | 23.09ᵃ                   | 62.33ᵇ                    |
| fertilizer        | Cow manure               | 0.69ᵃ      | 0.79ᵃ       | 1.50ᵃ                    | 44.91ᵃ                    | 61.46ᵃ                    |
| Green manure      | 0.72ᵃ                    | 0.78ᵃ      | 1.35ᵃ       | 17.53ᵃ                   | 55.66ᵃ                    |
The application of fertilizer did not influence Available K (table 3). Potassium sources other than the mineralization of given organic matter, the K element could be derived from primary mineral weathering [21]. However, the application of inorganic fertilizer and cow manure actually lower K levels than control. Potassium soil was mobile so easily lost through the process of leaching or carried away the flow of water movement [22].

The application of fertilizer significantly influenced the potassium content in roots but did not influence the potassium content in plant (table 3). Potassium content in roots ranged from 0.53–0.79% and only cow manure and green manure treatments significantly influenced the potassium content. Potassium content in plant ranged from 1.30 to 1.50%. Plant growing in water stress conditions had low potassium content in plant tissue, so fertilization was not effective.

Potassium uptake in roots ranged from 15.63 to 44.91 mg/clump with the treatment of cow manure that had the highest uptake. While potassium uptake ranged from 45.16 to 68.89 mg/clump in plant with combination of cow manure and green manure that had highest uptake. Application of potassium fertilizer would lead to increased potassium content in soil and would increase potassium uptake [23].

Table 4. The constant b and a (in mg·kg⁻¹) of various kinetic models for different treatments.

| Treatments | Power Function | Parabolic Diffusion | First-order Reaction | Elovich Equation | Zero-order Reaction |
|------------|----------------|---------------------|----------------------|------------------|-------------------|
|            | b   | a   | R²  | b   | a   | R²  | b   | a   | R²  | b   | a   | R²  | b   | a   | R²  |
| Cow        | 0.012a | 4.477* | 0.203* | 0.060* | 92.00* | 0.096* | 0.002* | 2.469* | 0.219* | 1.016ab | 88.51* | 0.190* | 0.064* | 2.448* | 0.165* |
| Infert.    | 0.008b | 4.485* | 0.190* | 0.293* | 89.65* | 0.180* | 0.007* | 2.396* | 0.232* | 0.768ab | 89.10* | 0.188* | 0.064* | 2.520a | 0.187b |
| Mix        | 0.013a | 4.536* | 0.233* | 0.213* | 94.77* | 0.140* | 0.004* | 1.493* | 0.169* | 0.812ab | 93.35* | 0.281* | 0.133* | 1.615* | 0.161* |
| Cow+green  | 0.003a | 4.489* | 0.443* | 0.613* | 90.84* | 0.562* | 0.002* | 2.089* | 0.126* | 1.779ab | 88.95* | 0.429* | 0.083* | 2.189* | 0.142* |

Data followed by the same letter in the column are not significantly different at the P<0.05 level, according to Duncan’s test.

All treatment had value of constant b (release rate) less than 1 (table 4) and only significantly influenced constant b in power function and Elovich equation models. The rate of potassium release decreased with time and similar results obtained from [24] research. Elovich equation model for release of non-exchangeable potassium had been reported by [8]. The application of fertilizer did not significantly influence constant a (potential of potassium release) but the highest value was parabolic diffusion model and the lowest value was zero-order reaction. Parabolic diffusion had the highest constant a compared to other models [14].

Power function, parabolic diffusion, first-order reaction, Elovich equation and zero-order reaction did not successfully describe the kinetic release of potassium. Green manure treatment showed that the highest coefficient of determination (R²) was power function model (0.443). Elovich equation, parabolic diffusion and power function models were the best of the kinetic equations to describe the K release pattern [25].

Organic fertilizer from decomposition resulted organic acids, such as acetit acid, lactic acid and oxalic acid [25]. Oxalic acid increased the reaction of destruction, release and potassium desorption [26] and oxalic acid significantly increased kinetic of potassium release from clay in soils dominated by smectite clay minerals [27]. Oxalic acid increased basal distance of smectite so that K⁺ became open and released from the bond [28]. Organic fertilizer contained fulvic acid and humic acid, beside oxalic acid. The organic acid in soils dominated by montmorillonite and illite increased K release up to 25% and increased basal distance from 11–11.9 Å (Humic acid) and from 11–12.3 Å (fulvic acid) [29].
4. Conclusion
The treatments were not significant on plant uptake, root uptake and K release so organic fertilizer can be used to replace inorganic fertilizer application. Among the five equations, power function best described the K release.

References
[1] Afany M R dan Partoyo 2001Jurnal Tanah dan Air2 88–96
[2] Calvert C S, Buol S W and Weed S B 1980Soil Sci. Soc. Am. J.44 1104–1112
[3] Eswaran H, Stoop G and De Paepe P 1973Pedologie23100–121
[4] Gilkes R J, Scholz G and Dimmock G M 1973J. Soil Sci.24 523–536
[5] Rice T J Jr, Buol S W and Weed S B 1985Soil Sci. Soc. Am. J.49 171–178
[6] Glassmann J R 1982Clay and Clay Min.30 253–263
[7] Sparks D L 1987Adv. Soil Sci.6 1–63
[8] Mengel K dan Uhlenbecker K 1993 Soil Sci. Soc. Am. J.57 561–566
[9] Jajali M 2006Geoderma135 63–71
[10] Sparks D L and P M Huang 1985Soil Sci. Soc. Am. 201–276.
[11] Najafi M and Ghiri 2014 Soil and Water Res1 31–37
[12] Shu-Xin T U, Zhi-Fen G U Oand Jin-He S U N 2007Pedosphere17 457–466
[13] Hosseinpur A R and Motaghiian H R 2013Pedosphere23 482–492
[14] Rao B K R 2014Solid Earth Discuss 6 2843–2865
[15]
[16] Tisdale S L and Nelson W L 1974 Soil Fertility and Fertilizer (New York: The Macmillan Publ Company)
[17] Notohadiprawiro T 1998 Tanah dan Lingkungan(Jakarta: Departemen Pendidikan dan Kebudayaan)
[18] Mallarino A 2000Soil Testing and Available Phosphorus(Lowa State University:Integrade Crop Management News)
[19] Hanafiah K A 2005 Dasar-dasar Ilmu Tanah(Jakarta: PT. Raja Grafindo Persada)
[20]
[21] Havlin J L, Beaton J D, Tisdale S L and Nelson W L 2005Soil Fertility and Nutrient Management7th Edition(Upper Saddle River:Perason Prentice Hall)
[22] Winarso S 2005Dasar Kesehatan dan Kualitas Tanah(Yogyakarta: Penerbit Gava Media)
[23] Darlison 1988Pengaruh pemberian kalium, sumber kalium dan kapur terhadap pertumbuhan, serapan hara, produksi dan kualitas biji kacang tanah (Arachis hypogea L.) pada Latosol Darmaga(Bogor: Fakultas Pertanian, Institut Pertanian Bogor)
[24] Jajali M 2008Geoderma145 207–215
[25] Ghiri M N 2014Soil and Water Res9 31–37
[26] Nursyamsi D, Idris K, Sabiham S, Rachim D A and Sofyan A 2008 Jurnal Tanah Tropika1433–40
[27] Nursyamsi D 2009Journal of Tropical Soils14 177–184
[28] Evangelou V P and Lumbanraja J 2002Soil Sci. Soci. Amer. J.66 445–455
[29] Tan K H 1978Geoderma21 67–74