

POTASSIUM ADSORPTION BEHAVIOUR OF THREE MALAYSIAN RICE SOILS

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Potassium (K) deficiency exists in different rice growing areas of Malaysia. A study on K adsorption was carried out in three Malaysian rice soils (Guar, Hutan and Kangar series) using six levels of K (0.00, 28.77, 33.57, 38.37, 43.16 and 47.96 mmol kg⁻¹). The data on K adsorption were fitted into Langmuir, Freundlich, and Temkin adsorption equations. Adsorption data were also correlated with pH, cation exchange capacity and organic matter content of the soils. Potassium adsorption increased linearly with increasing level of added K in all the three soils. The rate of increase was the highest in Guar series followed by Kangar and Hutan series, respectively. Potassium adsorption in two soils (Hutan and Kangar) fitted into Langmuir equation while the adsorption data in Guar series did not fit into this equation. Adsorption data in none of the soils fitted well in Freundlich and Temkin adsorption equations. Correlation between K adsorption and pH was significant ($r = 0.881$), whereas, correlation of K adsorption with either organic matter content or cation exchange capacity was non-significant. The results of this study indicated that K adsorption is mainly dependent on soil pH. In soils with higher adsorption capacity, more K fertilizer may be needed to get immediate crop response.

Key words: Potassium, Adsorption, Malaysian rice soils, Langmuir equation.

Introduction

Potassium is a major nutrient element for rice crop. Potassium requirement of rice crop is high (De Datta 1981; Sahrawat 2000). Cropping without K fertilization deplete K content of soil and consequently rice crop suffers from K deficiency (Anon 1993; Anon 1996). The largest rice growing area of Malaysia is located in Muda Irrigation Scheme, Kedah. This irrigation scheme covers an area of about 95,000 hectare. Recent investigations showed that K deficiency exists in many sites of this irrigation scheme (Choudhury and Khanif 1998 and 2000a). Therefore K fertilization is important to meet the K requirement of rice crop in this area.

When K, as a fertilizer, is applied to the soil, most of it is adsorbed by the soil and due to electrostatic attraction, covalent bonding or isomorphous replacement in the crystal lattice (Ponnamperuma 1978). This sorption phenomenon depends on soil characteristics (Choudhury and Khanif 2000b). Investigations showed that K adsorption is generally higher in soils with higher pH (Varbanova and Bache 1975). It is necessary to know the K adsorption behavior of the soils before K fertilization. With this view in mind, this study was undertaken to determine the K adsorption behavior of three rice soils, varying in pH, organic matter content and cation exchange capacity.

Materials and Methods

A laboratory experiment was conducted at Universiti Putra, Malaysia to evaluate the K adsorption behavior of three rice soils, differing in pH, organic matter content and cation exchange capacity. Description of the soils is presented in Table 1. Mineralogical class of Hutan series is kaolinitic, whereas it is mixed for the other two soils (Paramanathan 1998). The clay fraction of Hutan series is mainly composed of kaolinite with low amount of smectite. Kaolinite, smectite, micas and traces of quartz are present in the clay fraction of both Guar and Kangar series (Azmi 1982).

Soil collection and analyses. Soil samples were collected from rice growing areas under muda irrigation scheme, Kedah, Malaysia. The samples consisted of two marine alluvial and one riverine alluvial soils. Soil samples were collected from 0-15 cm depth. The soils were air dried, ground and sieved through 2 mm sieve. Soils were analysed for organic matter, pH, cation exchange capacity (CEC), total N, available P, exchangeable K, Mg and Ca, available Zn and Cu. Properties of the soils are given in Table 2. Organic matter was analysed by potassium dichromate and H₂SO₄ digestion method (Walkley and Black 1934). Soil pH was measured by glass electrode (Peech 1965). Total N was determined by sulphuric-salicylic acid digestion method (Bremner and Mulvaney 1982). Avail-

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able P was determined by $\text{NH}_4\text{F-HCl}$ extraction method (Bray and Kurtz 1945). Cation exchange capacity, exchangeable K, Mg and Ca were determined by ammonium acetate extraction method (Schollenberger and Simon 1945). Available Zn and Cu were analysed by 0.05 N HCl extraction method (Ponnamperuma *et al* 1981).

Adsorption procedure. 4 g of each soil were weighed into different centrifuge tubes. Different concentrations of K solutions (0, 150, 175, 200, 225 and 250 mg K l^{-1}) were prepared by dissolving KCl in distilled water. 30 ml of K solution with different concentrations were added to 4 g soil in the centrifuge tubes to obtain 0, 28.77, 33.57, 38.37, 43.16 and 47.96 mmol kg^{-1} added K. Each treatment was replicated three times. The experiment was conducted using completely randomised design (CRD). The tubes were covered tightly by lid and incubated at room temperature (25-30°C) for 15 days. Fifteen day period incubation was provided to attain an equilibrium condition for K adsorption. Preliminary studies indicated that equilibrium condition for K adsorption in these soils could be attained by 15 days incubation.

After 15 days, the tubes were centrifuged and the supernatant solutions were filtered and analysed for K by atomic

absorption spectrophotometer. K concentration after solution were calculated as milli mole per litre (mmol l^{-1}). The amount of K adsorbed per gram of soil (x/m) was calculated from the difference in K concentration in initial added K solution and the supernatant equilibrium solution (C) taking into account the amount of K present in solution in the control (non potassium) treatment. The adsorbed K was calculated as milli mole per kilogram mmol Kg^{-1} .

Adsorption isotherm. Data on adsorption of K in soils were fitted into following adsorption equations:

1. **Langmuir Adsorption Equation.** This equation is used to calculate maximum adsorption capacity of a soil for adsorbing an element. It is important to know the maximum adsorption capacity of a soil for adsorbing an element to get a preliminary idea about fertilization practice. The equation is as follows:

$$C/(x/m) = 1/kb + c/b \quad \dots\dots\dots (1)$$

Where, C is the equilibrium of K solution (mmol l^{-1}), x/m is the mass of K adsorbed per unit mass of soil (mmol kg^{-1}), k is a constant related to bonding energy of K to the soil, b is the maximum K adsorption capacity (mmol kg^{-1}) of the soil. A plot

Table 1
Potasium (K) adsorption behaviour in three rice soils

Soil series	Location	Taxonomic class ¹	Parent material
Guar	Teluk cempedak	Typic sulfaquept, very fine clayey, mixed, isohyperthermic, brown.	Marine alluvium
Hutan	Gajah mati	Aeric plinthic kanahaplaqualt, fine clayey, kaolinitic, isohyperthermic, pallid.	Riverine alluvium
Kangar	Batu pahat	Typic endoaquert, very fine clayey, mixed, isohyperthermic, pallid.	Marine alluvium

¹Paramanathan (1988).

Table 2
Selected properties of the soils used for K adsorption study

Properties	Guar	Hutan	Kangar
Organic Matter (%)	5.61	1.82	1.99
pH	3.20	3.60	7.50
Cation exchange capacity (mol kg^{-1})	13.48	7.15	9.13
Total N (%)	0.16	0.07	0.06
Available P (mg kg^{-1})	6.80	31.10	3.60
Exchangeable K (mol kg^{-1})	0.32	0.13	0.08
Exchangeable Mg (mol kg^{-1})	0.29	0.09	0.34
Exchangeable Ca (mol kg^{-1})	2.09	1.93	8.11
Available Zn (mg kg^{-1})	1.58	2.99	0.08
Available Cu (Mg kg^{-1})	0.15	3.10	0.04

of $C/(x/m)$ versus c gives a straight line. The constants b and k are obtained from the slope ($1/b$) and the intercept ($1/kb$), respectively.

2. *Freundlich Equation*. This is a modified form of Langmuir equation. It is as follows:

$$x/m = a^{cb} \dots\dots\dots (2)$$

By rearranging

$$\log(x/m) = \log a + b \log c \dots\dots\dots (3)$$

Where, x/m is the mass of K adsorbed per unit mass of soil (mmol kg^{-1}), C is the equilibrium of K solution (mmol l^{-1}), a and b are constants. A plot of $\log(x/m)$ versus $\log C$ gives a straight line. The constants a and b are obtained from the intercept ($\log a$) and slope (b), respectively.

3. *Temkin Equation*. This equation is used to calculate the buffering capacity (retention capacity of adsorbed nutrient) of soil. The equation is as follows:

$$x/m = a + b \ln C \dots\dots\dots (4)$$

The b value of Temkin equation is considered as the K buffering capacity (retention capacity of adsorbed K) of soil (mmol kg^{-1}).

4. *Statistical Analysis*. Necessary statistical analyses of the data were done using Statistical Analysis System (Anon 1987).

Results and Discussion

Equilibrium of K solution concentration increased linearly with increasing of potassium (K) rates in all the soils with significant R^2 values (Fig 1). However, the rate of increase was the highest in Hutan series followed by Guar and the lowest in Kangar. Variations are noted among the soils in equilibrium of K solution concentration. This variation was due to difference in K adsorption. As adsorption was highest in Kangar series (Fig 2), potassium (K) solution concentration was lowest in this soil (Fig 1). Differences in equilibrium of K solution concentration among soils were found in previous investigations (Baligar 1984; Singh *et al* 1987).

1. *Potassium adsorption*. Potassium adsorption increased linearly with increasing levels of added K in all the soils with significant R^2 values (Fig 2). However, the rate of increase in adsorption was the highest in Guar series followed by Kangar and the lowest in Hutan. Variations are noted among the soils in K adsorption. Correlation analysis indicated that relationship between K adsorption and pH was positive and significant ($r = 0.881$), while the relationship between K adsorption with either organic matter content ($r = -0.075$) or cation exchange capacity ($r = 0.195$) was not significant.

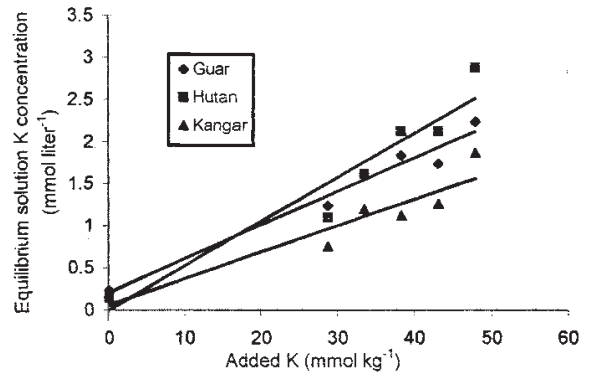


Fig. 1 Effect on equilibrium of K solution concentration of the soils on addition of K.

$y, 0.205 + 0.04 x; R^2, 0.9671^{**}$ (Guar); $y, 0.004 + 0.0525 x; R^2, 0.912^{*}$ (Hutan); $y, 0.0513 + 0.0513 x; R^2, 0.8793^{**}$ (Kangar)

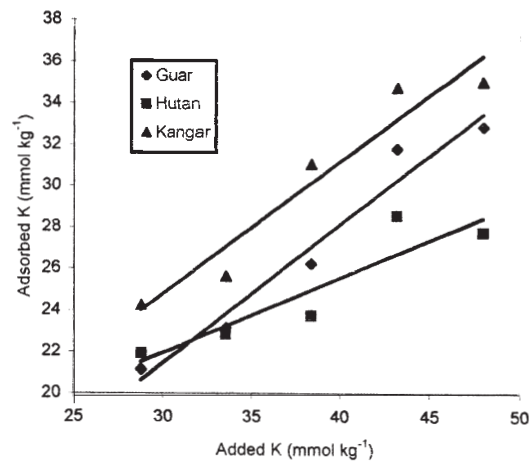


Fig. 2 Effect K addition on K adsorption in the soils.

$y, 1.3683 + 0.6695 x; R^2, 0.9612^{**}$ (Guar); $y, 11.1 + 0.3616 x; R^2, 0.8403^{*}$ (Hutan); $y, 5.5909 + 0.6406 x; R^2, 0.9321^{**}$ (Kangar)

The clay fraction of all the soils contains kaolinite (Azmi 1982). At higher pH, the OH^- ion dominates in the soil solution. There are also OH^- ions at the broken edges of kaolinite. Due to abundance of OH^- in soil solution, it takes one H^+ from the OH^- present on edges of kaolinite to form H_2O . As a result, negative charge develops at clay lattice, which contributed in more cation adsorption (Brady 1990). Similarly at higher pH, OH^- of soil solution takes one H^+ from carboxyl and phenolic groups of organic matter to form H_2O . Consequently more negative charges are developed which contributed in more cation adsorption. This might be reason for positive relationship between K adsorption and pH. Since Kangar series had higher pH and adsorption than Hutan series, (Table 4). Thus, the diffusion of K would be faster in Hutan series compared to Kangar series. Both the soils (Hutan and Kangar) are deficient in K and more K fertilizer may be needed in Kangar series to get immediate crop response. Previous

investigations showed K adsorption was higher due to higher pH in soil (Varbanova and Bache 1975). Differences among the soils for K adsorption were found in other investigations (Brady 1990; Sparks and Rehcigl 1982).

2. Adsorption isotherm. The data on K adsorption in both Hutan and Kangar series fitted well in Langmuir equation (Table 3) while the K adsorption data of Guar series did not fit in Langmuir equation. Coefficient of determination (R^2 value) was significant at 1% and 5% levels of probability for Hutan and Kangar series, respectively. None of the soil's K adsorption data fitted well in Freundlich and Temkin adsorption equations, R^2 values for all the soils were non-significant.

Maximum K adsorption capacity was $34.13 \text{ mmol kg}^{-1}$ in Hutan series while it was $50.25 \text{ mmol kg}^{-1}$ in Kangar series (Table 4). An increase of $16.12 \text{ mmol kg}^{-1}$ in maximum adsorption capacity was noted in Kangar series over Hutan series. Constant of energy of adsorption (K value) was 1.46 in Hutan series while it was 1.24 in Kangar series. An increase of 0.22 in K value was noted in Hutan series over Kangar series. As K

adsorption data in Guar series did not fit in Langmuir equation, the maximum adsorption capacity and K value were not obtained for this soil.

Langmuir equation was derived based on the assumption that there is a constant energy of adsorption, which is independent of surface coverage. This situation does not occur always in nature (Bohn *et al* 1979). This might be the possible reason for which the K adsorption data in Guar series did not fit in Langmuir equation.

Farmers are applying a single rate of K ($20 \text{ kg K}_2\text{O h}^{-1}$) throughout the muda irrigation scheme. But K fertilization should be practised based on soil K status and adsorption characteristics. In soil, deficient in K and having higher K adsorption capacity, more K fertilizer should be applied to get immediate crop response. Due to high K requirement of rice crop, K content of rice soils deplete in long run if rice is grown without K fertilization (Kemmler 1980; Ahsan *et al* 1997). So, a lower doze of K fertilizer should be applied even in K rich soils and lower K adsorption capacity to maintain soil K status.

Table 3

Regression equations and R^2 values for Langmuir, Freundlich and Temkin adsorption isotherms for K adsorption in the soils

Soil	Adsorption isotherm	Regression equation	R^2 value
Guar	Langmuir	$y = 0.0490 + 0.0090x$	0.201 ^{ns}
	Freundlich	$y = 1.2490 + 0.76060x$	0.718 ^{ns}
	Temkin	$y = 16.3570 + 20.0530x$	0.692 ^{ns}
Hutan	Langmuir	$y = 0.0201 + 0.0290x$	0.920 ^{**}
	Freundlich	$y = 1.3230 + 0.2646x$	0.651 ^{ns}
	Temkin	$y = 20.8450 + 6.5580x$	0.627 ^{ns}
Kangar	Langmuir	$y = 0.0160 + 0.0200x$	0.771 [*]
	Frundlich	$y = 1.4439 + 0.4080x$	0.606 ^{ns}
	Temkin	$y = 28.2790 + 11.4960x$	0.586 ^{ns}

** , Significant at 1% level; * , significant at 5% level; ns, non-significant.

Table 4

Maximum adsorption capacity and constant of energy of adsorption in Hutan and Kangar soils

Soil	Maximum adsorption capacity*(mmol kg^{-1})	Constant of energy of adsorption**(k value)
Hutan	34.13	1.46
Kangar	50.25	1.24

*, Calculated b value from Langmuir equation; **, Calculated K value from Langmuir equation. In Guar soil, adsorption data did not fit in Langmuir equation.

Conclusion

The finding of this study indicate that K adsorption varied among the soils. Maximum K adsorption capacity is higher in soil with higher pH. In soils with higher adsorption capacity, more K fertilizer may be needed to get immediate crop response.

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