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Comparison of potassium quantity-intensity relationships in tropical paddy soil under tillage and no-tillage systems after fifteen growing seasons

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Abstract: The information on the behaviour of potassium (K^+) in tropical paddy rice soils, which is important for a better understanding of the plant availability of K^+ is still very limited. We compared the quantity-intensity (Q/I) relationships for K^+ under conventional tillage and no-tillage systems in tropical paddy fields in the absence and presence of K^+ fertiliser in the addition of nitrogen. The results showed that the values of the activity ratio for K (AR_K) and potential buffering capacities (PBC_K) in the no-tillage rice field were respectively 16% and 33% higher than that in the conventional tillage field. With the addition of K fertiliser, the value of exchangeable K in equilibrium (ΔK^0) in the no-tillage paddy field was 67.9% greater than that in the conventional tillage field. This indicates that K fertilisation is more efficient when applied on a no-tillage paddy field. When the K fertiliser was added (49.8 kg K/ha), the application of N fertiliser at the rate of 115 and 184 kg N/ha resulted in a higher AR_K value than that at the rate of 46 kg N/ha. This suggests that the simultaneous application of K and N fertiliser was able to increase exchangeable K in the soil. The application of no-tillage increased of the dry grain yield of rice (about 10%) compared with the application of conventional tillage. Meanwhile, there were significant relationships between the rice yield with the AR_K and ΔK^0. Moreover, the AR_K was significantly correlated with K-uptake.

Keywords: puddled soil; essential nutrient; exchangable K; buffer capacity; *Oryza sativa* L.

In lowland rice (*Oryza sativa* L.) cultivation, soil puddling will make rice roots easy to develop, making it easier to do seedling transplanting (Huang et al. 2016). However, plowing causes soil particles and nutrients to drift along with water flow. This results in increased water sedimentation and decreased decomposition rate of organic matter (Sharma and De Datta 1985). Therefore, it is not surprising that in many Asian rice-producing countries, the environmental damage to agricultural lands is directly or indirectly caused by intensive rice production with perfect soil tillage that has been happening for decades (Reddy and Hukkeri 1983).

Weeds in lowland rice cultivation reduce rice yields not only because they compete for soil nutrients, moisture, and sunlight but also because they may be an alternate host for insects and diseases of rice. Normally, weed control requires a lot of labour (Lhungdim et al. 2019); hence the use of chemicals (herbicides) for weed control before planting worth to be trying (Gangireddy and Subramanyam 2020). The soil tillage activities for rice cultivation in paddy fields do not absolutely require tillage because the availability of water in paddy fields can actually help the puddling process (Prasanthkumar et al. 2021).

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For preparing the soil to plant rice, the most important thing is that the paddy field must be clean of weeds. Some studies have reported that weed control using herbicides is quite effective and can save labour (Prasanthkumar et al. 2021). The application of conservation tillage (no-tillage) saves soil and water and can save energy, costs, and time (Neugschwandtner et al. 2014, Çay 2018). Moreover, the required labour may be reduced, and farmers' income may be increased.

Soil tillage can affect the amount of organic matter (Çay 2018), soil nitrogen (N), and potassium (K) in the soil solution, in addition to the adsorption process by clay minerals (Denardin et al. 2019). The ammonium ion (N-NH_4^+) and the potassium ion (K^+) resulting from the decomposition of organic matter and the fertilisation of urea and KCl can be adsorbed by clay minerals. The K^+ ion strongly influences the buffering capacity of N-NH_4^+ in the soil solution (Han et al. 2020). The adsorption of the two ions in the soil can be studied using the relationship between quantity-intensity ratio (Q/I ratio) (Beckett and Nadafy 1967). Sparks and Huang (1985) suggested that the Q/I ratio has been widely used to study the soil K status.

Many studies using quantity-intensity (Q/I) techniques have been conducted to determine the ability of soils to maintain the supply of K^+ to plants. The information from the studies is important for a better understanding of the plant availability of K^+ in the soil solution (Beckett and Nafady 1967). Furthermore, studies on the relationship between tillage or accumulation of organic matter and the exchange characteristics of K^+ have been carried out, especially on dryland in the subtropical areas (Scherer et al. 2014, Panda and Patra 2018), while on wetlands (rice paddy fields) it is still rarely done (Evangelou et al. 1994, Taiwo et al. 2010, Scherer et al. 2014, Islam et al. 2017, Cay 2018). Information on the behaviour of K^+ in paddy soils, both from fertilisers and organic matter, and soil minerals and its relationship to tropical rice cultivation is still very limited. This information is required, indeed, to devise appropriate management practices for the rice paddy soils. Therefore, the objective of the study reported in this paper was to compare the Q/I of K^+ of conventional tillage and no-tillage paddy fields, either with or without K, at several N fertiliser rates.

MATERIAL AND METHODS

Site description. The experiment was started in August 2011 (dry season) on an irrigated rice paddy field for a long-term experiment of soil tillage systems and nitrogen application at Kedaloman village, Tanggamus District, Lampung province, Indonesia, located at 500 m a.s.l., with coordinates 104°45'44''E and –5°23'15''S.

The soil profile analysis showed that the soil classification at the experimental site, according to Soil Survey Staff (1999), is in Order Inceptisols, Sub-order Aquepts, Great Group Fragiaquepts, Subgroup Aeric Fragiaquepts, Family Aeric Fragiaquepts. The soil texture at 0–20 cm depth is clay (14.8% sand, 37.5% silt, and 47.7% clay). The composite soil samples were taken from the three blocks before planting and fertiliser application (one day after the paddy fields were submerged). Selected chemical properties of the soil are presented in Table 1.

The climate of the Kedaloman village is warm and humid (with a mean annual relative humidity of 70–80%), the mean annual rainfall is approximately 3 000 mm, and the mean annual temperature is 28 °C. During the experimental period (2018), the average rainfall during the rainy growing season was below 10 mm/month. Irrigation water used in the experimental area was obtained from the Way Bekhak River subsystem that was available all year round.

Experimental design and treatments. The present study was conducted from May to August 2018 (the 15th growth season). The experiment was a factorial, arranged in a randomised completely block design. There were three factors: (1) tillage system (t): conventional tillage (CT) and no-tillage (NT) rice paddy field; (2) potassium fertiliser: without K and 49.8 kg K/ha; and (3) nitrogen fertiliser: 46, 115, and 184 kg N/ha. The treatments were replicated three times. Plot sizes were 3 × 4 m^2.

For the no-tillage system, weeds and stumps were sprayed with the herbicide, i.e. glyphosate, with a spray volume of 500 L/ha solution; a week after spraying, the soil was flooded for 21 days. For conventional tillage, the soil is hoeed once (0–20 cm depth) and then flooded for one week, hoeed again, then harrowed, and the soil was flooded for 14 days, and the land was ready to be planted with rice seedlings. Cultivar IR64 rice seedlings were planted between two rice stumps for the no-tillage system, whereas for conventional tillage, they were planted at a distance of 25 cm × 25 cm (approximately 16 000 clumps/ha) as many as 3 stems/hole; only 3 stems were reared (thining was done at 15 days after planting (DAP)). The urea prill fertiliser was given in stages according to the treatment, namely 1/3 part at planting, 1/3 part

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Table 1. Selected properties of the soils (at soil depths of 0–10 cm) the day after flooding at the Kedaloman Village, Tanggamus District, Lampung province

Treatment	pH_{H_2O}	pH_{KCl}	C_{org}	N_{tot}	Ratio C:N	CEC	K^+	Mg^{2+}	$N\text{-}NH_4^+$	Bray-2 P	Fe	Mn
			(g/kg)			($cmol_+$/kg)			(mg/kg)			
Control	5.96	5.32	14.00	0.90	15.56	9.35	0.21	5.63	88.35	7.12	43.70	23.89
CtK_0N_1	5.95	5.35	12.30	1.30	9.46	15.68	0.31	5.64	187.26	5.21	69.02	42.04
CtK_0N_2	5.75	5.22	13.20	1.20	11.00	16.36	0.38	4.85	85.23	3.61	59.52	15.76
CtK_0N_3	6.21	5.20	13.30	1.30	10.23	19.00	0.30	5.34	61.13	4.93	63.29	16.56
CtK_1N_1	5.83	5.30	13.00	1.40	9.29	17.75	0.36	4.71	88.61	3.30	66.30	27.07
CtK_1N_2	6.39	5.12	12.40	1.40	8.60	14.59	0.30	4.77	120.42	4.22	67.06	10.76
CtK_1N_3	6.24	5.34	14.10	1.30	10.85	17.67	0.35	5.18	130.35	3.71	60.28	14.90
NtK_0N_1	6.32	5.48	12.70	1.20	10.58	17.62	0.24	5.45	94.03	5.42	45.21	10.13
NtK_0N_2	6.62	5.35	14.70	1.30	11.31	15.89	0.24	5.05	140.91	6.33	50.63	13.69
NtK_0N_3	6.74	5.45	13.80	1.30	10.62	15.30	0.24	5.23	204.52	6.01	38.43	7.96
NtK_1N_1	5.56	5.32	13.30	1.60	8.31	16.71	0.24	4.99	125.50	5.21	51.24	11.60
NtK_1N_2	6.16	5.48	13.80	1.40	9.86	14.87	0.23	5.02	119.31	4.62	40.69	18.15
NtK_1N_3	6.25	5.31	14.70	1.40	10.50	16.86	0.25	5.18	112.02	4.51	42.19	20.32

Ct – conventional tillage; Nt – no-tillage; K_0 – 0 kg K/ha; K_1 – 49.8 kg K/ha; N_1 – 46 kg N/ha; N_2 – 115 kg N/ha; N_3 – 184 kg N/ha; C_{org} – organic carbon; N_{tot} – total nitrogen; CEC – cation exchange capacity

at 21 DAP, and the rest at flower primordia (42 DAP). SP-36 fertiliser was given at the same time as 1/2 dose of KCl fertiliser, while 1/2 dose of KCl was given at 21 DAP. The application of urea, SP-36, and KCl were evenly distributed. Maintenance was carried out intensively; carbofuran 30 g/kg was given at planting and flower primordia. Weeding was carried out any time after the observed weed density was at 21 DAP, which was manifested as a weed (g/m^2) using a.i. methyl metsulfuron 200 g/kg.

Soil sampling. The soil samples were collected at the flowering time (42 DAP), using a 2-cm diameter soil corer. Ten soil cores per plot were taken (diagonally) at soil depths of 0–10 cm, and the cores for each treatment were combined. All soil samples were air-dried and passed through a 2-mm sieve to remove debris (obvious root and straw). The sieved samples were stored for chemical analyses to determine the Q/I relationship of potassium. Samples of soil had also been collected from the three blocks before the experiment started and were analysed to determine soil properties before starting the trials.

Chemical analysis. The soil pH was measured in a water suspension (using a soil:solution weight ratio of 1:2.5) after the suspensions were shaken for 24 h on a reciprocal shaker. The organic matter content of the soils (expressed as percentage carbon) was determined by heating the samples in a stream of high-purity oxygen in a Leco furnace to produce CO_2. The CO_2 was measured with an infrared detector (Leco Co. 1996), and the quantity of that gas was used to determine the total organic carbon. Cation exchange capacity (CEC) and exchangeable cations were determined by ammonium acetate leaching at pH 7 (Blakemore et al. 1987). The concentrations of K and Ca in the leachates were determined by atomic absorption spectrometry (AAS), and the ammonium concentration was determined using an autoanalyser (Blakemore et al. 1987).

Adsorption of K^+ in paddy soil samples was evaluated using the quantity-intensity (Q/I ratio) method (Evangelou et al. 1986, Lumbanraja and Evangelou 1990). Initially, five series of KCl solutions with a concentration of 0, 1, 2, and 3 mmol/L were prepared in a $CaCl_2$ solution with a 5 mmol/L concentration. The initial K^+ content in the series solution was measured. Each sample of wet soil (with known moisture content) was weighed as much as 5 g and put into a series of centrifuge bottles (the same amount as the KCl series solution). Then, 50 mL of each solution of the KCl series was added and shaken for 6 h. The soil suspension was centrifuged at 1 500 revolutions/min. Each treatment series was carried out in duplicate. The clear solution obtained was analysed

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to determine Ca + Mg, and electrical conductance (EC) was measured by AAS and conductivity meter, respectively, while K^+ was determined by flame photometer. The measured cation concentration is the cation in equilibrium.

The calculation for adsorbed potassium. The K^+ activity ratio (AR_K) is calculated using the formula:

$$AR_K = (K^+)\gamma_K + /((Ca + Mg)\gamma_{Ca + Mg})^{1/2} \quad (1)$$

The value in parentheses indicates the concentration of a particular ion in equilibrium, and γ_i shows the coefficient of single ion activity, that is, by entering the value of ionic strength (I). The value of I can be calculated using the empirical formula proposed by Griffin and Jurinak (1973) as follows:

$$I = a(EC) \quad (2)$$

I – ionic strength of the solution (mol/L); EC (mmhos/cm) – electrical conductivity, and *a* – constant of 0.013 for an aqueous solution (I < 0.1 mol/L). Then γ_i can be calculated using the Davies equation by entering the value of the ion charge (Zi) (Sparks 1995):

$$\log \gamma_i = -AZi^2[I^{0.5}/(1 + Ba_iI^{0.5})] \quad (3)$$

The values of A = 0.50 and B = 0.33 at 25 °C correspond to the dielectric constant, while a_i is taken from Sparks (1995) by correcting from the units A° to nm by dividing by 10.

The change value of exchangeable K (ΔK) is the difference between the K^+ concentration before and after equilibrium with soil colloids. From the processing of observational data, the values of exchangeable K (ΔK), AR_K^0 (activity ratio of K^+ at equilibrium), ΔK^0 (exchangeable K in equilibrium), and PBC_K values (potential buffer capacity for K) were obtained. The selectivity of K^+ is seen from the value of the Gapon coefficient, namely $K_G = 1/2(PBC_K)/(CEC)$ (Evangelou and Karathanasis 1986, Evangelou et al. 1994). The value of Ks (potassium adsorbed in a specific site) was calculated based on the reduction between the exchangeable K value of the extraction method 1 mol/L $NH_4C_2H_4O_2$ pH 7.0 and ΔK^0 (K – labile) as follows:

$$Ks = K_{ex}\ (1\ mol/L\ NH_4C_2H_4O_2\ pH\ 7.0) - \Delta K^0 \quad (4)$$

The Q/I ratio of potassium was analysed by linear regression, while to see the difference between each method of tillage, the misalignment and non-conformance tests were used (Draper and Smith 1961). All tests are at the 0.05 level of significance.

RESULTS AND DISCUSSION

The results of the ratio of potassium activity (AR_K) in the present study ranged from 0.0164–0.0358 $(mol/L)^{1/2}$ (Table 2; Figures 1 and 2). In the no-

Table 2. The equation of the potassium quantity-intensity (Q/I) curve and the parameter values related to the two soil tillage systems fertilised with N and K

Soil tillage	Fertiliser (kg/ha) K	Fertiliser (kg/ha) N	Regression	R^2	PBC_K $cmol_+/kg/(mol/L)^{1/2}$	AR_K $(mol/L)^{1/2}$ ($\times 10^{-2}$)
Conventional tillage	0	46	$Y = 3.91X - 0.09$	0.93	3.91[b]	2.31
No-tillage	0	46	$Y = 4.94X - 0.16$	0.98	4.94[a]	3.22
Conventional tillage	0	115	$Y = 4.01X - 0.13$	0.96	4.01[b]	3.32
No-tillage	0	115	$Y = 5.18X - 0.17$	0.98	5.18[a]	3.23
Conventional tillage	0	184	$Y = 4.14X - 0.13$	0.94	4.14[b]	3.19
No-tillage	0	184	$Y = 5.20X - 0.18$	0.98	5.20[a]	3.44
Conventional tillage	49.8	46	$Y = 4.02X - 0.06$	0.92	4.02[b]	1.64
No-tillage	49.8	46	$Y = 5.11X - 0.16$	0.99	5.11[a]	3.12
Conventional tillage	49.8	115	$Y = 3.74X - 0.12$	0.94	3.74[b]	3.33
No-tillage	49.8	115	$Y = 5.15X - 0.18$	0.98	5.15[a]	3.42
Conventional tillage	49.8	184	$Y = 3.66X - 0.13$	0.96	3.66[b]	3.52
No-tillage	49.8	184	$Y = 5.60X - 0.20$	0.96	5.60[a]	3.58

The number of PBC_K followed by the same letters is not different according to the non-differentiation test of the equation between conventional tillage and no-tillage. PBC_K – potential buffer capacity of potassium (slope of the regression line); AR_K – potassium intensity in equilibrium; X – AR_K is potassium intensity (I); Y – ΔK is the change of exchangeable potassium (Q)

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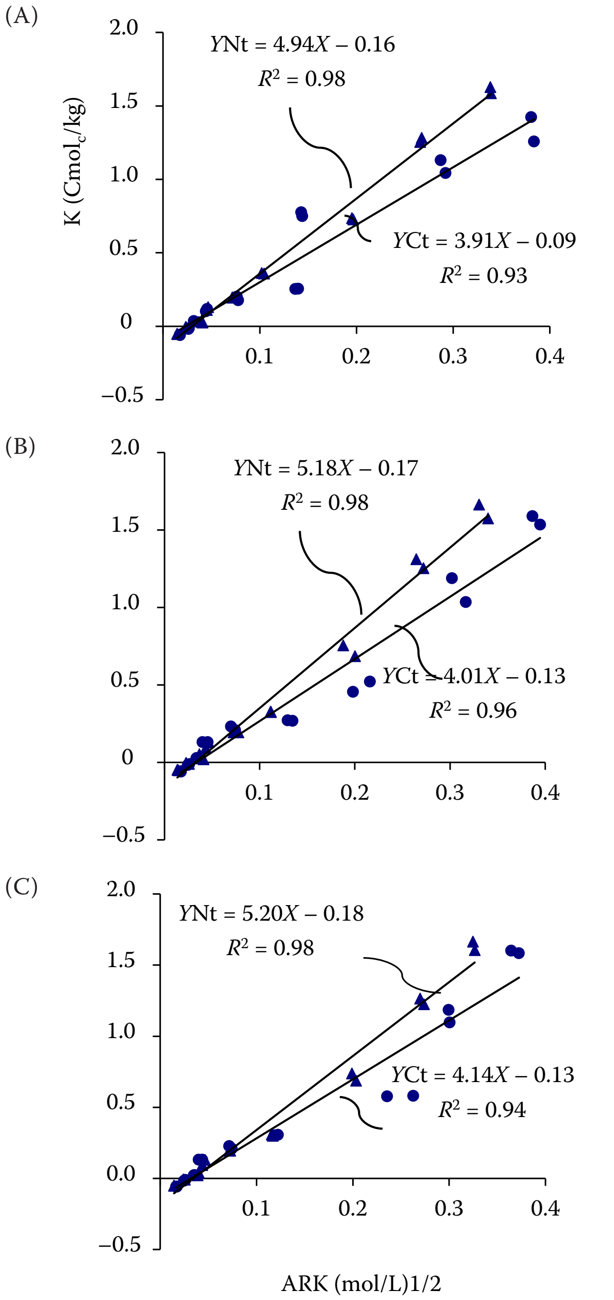

Figure 1. Quantity-intensity (Q/I) of potassium (K) under conventional tillage (Ct, •) and no-tillage (N_t, ▲) without potassium (0 kg K/ha) and at the application of (A) 46 kg N/ha; (B) 115 kg N/ha, and (C) 184 kg N/ha

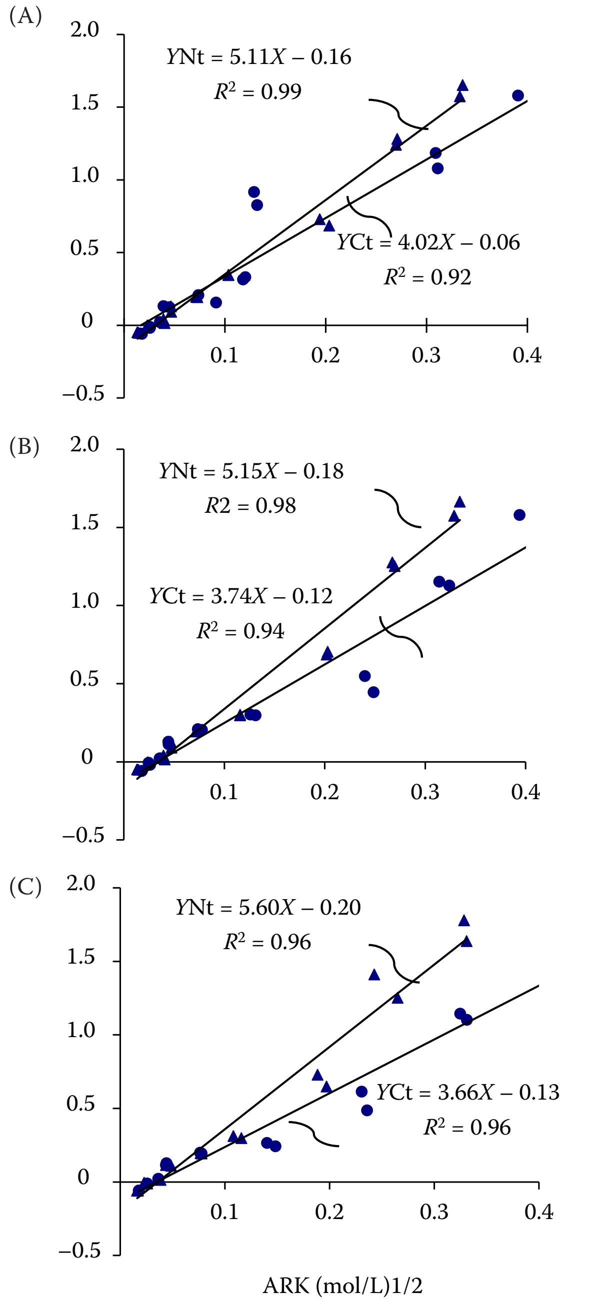

Figure 2. Quantity-intensity (Q/I) of potassium (K) under conventional tillage (Ct, •) and no-tillage (N_t, ▲) with the addition of 49.8 kg K/ha and at the application of (A) 46 kg N/ha; (B) 115 kg N/ha, and (C) 184 kg N/ha

tillage system, at all levels of N for both with and without K fertiliser application, the AR_K value was about 16% higher than that in the conventional tillage system. Meanwhile, the PBCK value was about 33% higher in the no-tillage system than in the conventional tillage system. The high correlation value (r = 0.81*) between the ratio of AR_K and the exchangeable K in equilibrium (ΔK^0) indicates that K-labile greatly determines the availability of K in equilibrium (Table 3). Van Schouwenburg and Schuffelen (1963) suggested that theoretically, if the ratio of potassium activity (AR_K) value < 0.001, K is adsorbed at the "wedge" position or between layers (interlatice) and if the ratio of potassium activity value > 0.01, so K is

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Table 3. Correlation between quantity-intensity (Q/I) curve parameters and soil properties, biomass weight, and nutrient uptake

Correlation (*n* = 12)	ΔK^0	PBC^K	K_G	CEC	C_{org}	Exch. K	Crop biomass	N-NH_4^+	Uptake		Yield (dry grain)
									K	N	
AR_K	0.81*	0.34ns	0.10ns	0.55ns	0.58*	0.64*	0.68*	0.47ns	0.63*	0.69*	0.75*
ΔK^0	1.0	0.82*	0.32ns	0.74*	0.80*	0.59*	0.40 ns	0.36ns	0.33ns	0.48 ns	0.71*
PBC^K		1.0	0.64*	0.65*	0.70*	0.29ns	0.05ns	0.09ns	0.12ns	0.07ns	0.40ns
K_G			1.0	0.17ns	0.14ns	0.31ns	0.62*	0.45ns	0.67*	0.56ns	0.27ns
CEC				1.0	0.76*	0.68*	0.56ns	0.55ns	0.52ns	0.66*	0.78*
C_{org}					1.0	0.78*	0.53ns	0.57ns	0.49ns	0.64*	0.78*
Exch. K						1.0	0.76*	0.89*	0.73*	0.83*	0.84*
Biomass							1.0	0.71*	0.99*	0.97*	0.76*
N-NH_4^+								1.0	0.71*	0.76*	0.69*
K uptake									1.0	0.96*	0.72*
N uptake										1.0	0.85*

*significantly different at $\alpha = 0.05$; ns – not significantly different; AR_K – potassium intensity in equilibrium; ΔK^0 – change of exchangable potassium (–labile); PBC_K – potential buffer capacity of K; K_G – selectivity coefficient of K; CEC – cation exchange capacity; C_{org} – organic carbon

adsorbed in the planar position (flat), whereas if it is between 0.001–0.01, so K is adsorbed at the "edge" position. In the present study, the results of the AR_K values indicate that the bulk of the K adsorbed is in the planar as their values are > 0.01. Furthermore, Sparks and Huang (1985) reported that there was a close relationship between the ratio of potassium activity (AR_K) and the exchangeable K in equilibrium (ΔK^0), which can describe the availability of K in the soil.

In Table 2, it is shown that the addition of K (49.8 kg K/ha) did not increase the ratio of potassium activity compared with control (0 kg K/ha) (3.12 *vs.* 3.10 $(mol/L)^{1/2} \times 10^{-2}$). The present result is in line with the finding of a study conducted by Nafady and Lamm (1973). They found that the Q/I relationship for K was not affected by the addition of K fertiliser to close to 1 000 kg K/ha. On the contrary, other studies reported that increased the rate of K application increased the ratio of potassium activity (Beckett and Nadafy 1967, Das et al. 2018). The difference in results found between the present study and the latter is most likely to be due to the difference in the type of clay minerals used in the two studies. In the present study, the type of clay mineral is halloysit (type 1:1), while in the latter, the type of clay mineral is dominated by clay type 2:1. In type 2:1, soil K can be sourced from the clay mineral itself, while in type 1:1 only a small amount of K is contained in it.

The results in Table 2 also showed that at the application of K fertiliser (at the rate of 49.8 kg K/ha), the addition of 115 and 184 kg N/ha significantly gave a higher ratio of potassium activity (AR_K) values compared with the addition of 46 kg N/ha. This suggested that the application of K and N fertiliser simultaneously was able to increase the exchangeable K in soil (Table 4), in which at the application of 49.8 kg K/ha, the increase of N fertiliser rate increased exchangeable K, both in conventional tillage soils and no-tillage soils (0.29 *vs.* 0.31 and 0.42 $cmol_+$/kg for conventional tillage; 0.36 *vs.* 0.39 and 0.48 $cmol_+$/kg for no-tillage). In daily practice, local farmers apply N fertiliser much more often than K fertiliser, even though they never apply K fertiliser to their lands.

At the addition of K (49.8 kg K/ha), compared to the control (0 kg K/ha), the change of exchangeable K (ΔK^0) of the no-tillage (0.18 $cmol_+$/kg, the average of the three N rates) was higher than that of the conventional tillage (0.11 $cmol_+$/kg, the average of the three N rates), or increased by 63.6% (Table 3). This result indicates that K fertiliser is more efficiently applied to the no-tillage soils compared to the conventional tillage. In other words, K pools are easily available, or K-labile was larger in the no-tillage soils than that in the conventional tillage soils. According to Lumbanraja and Evangelou (1990), the exchangeable K in equilibrium (ΔK^0) is a better estimator of soil K-labile than normal exchangeable K determined with 1 mol/L $NH_4C_2H_4O_2$ pH 7.0.

The results in Table 3 showed that the relationship between the exchangeable K in equilibrium (ΔK^0) and

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Table 4. K-labile, Gapon coefficient, and K adsorbed at a specific site under the two soil tillage systems fertilised with N and K

Soil tillage	K	N	ΔK^0	K_G	Ks	$K_{ex.}$	K-uptake	Rice yield
	(kg/ha)		$cmol_+/kg$	$(mol/L)^{1/2}$	$(cmol_+/kg)$		(kg/ha)	(t/ha)
Conventional tillage	0	46	0.09^b	0.16	0.18	0.27	69.58	5.43
No-tillage	0	46	0.16^a	0.17	0.13	0.31	92.55	6.30
Conventional tillage	0	115	0.13^b	0.16	0.18	0.31	102.48	7.47
No-tillage	0	115	0.17^a	0.15	0.14	0.35	74.19	5.53
Conventional tillage	0	184	0.13^b	0.13	0.25	0.38	107.98	6.57
No-tillage	0	184	0.18^a	0.16	0.24	0.44	99.44	7.20
Conventional tillage	49.8	46	0.07^b	0.14	0.24	0.29	75.52	5.70
No-tillage	49.8	46	0.16^a	0.17	0.20	0.36	87.07	6.83
Conventional tillage	49.8	115	0.12^b	0.12	0.23	0.31	103.84	7.90
No-tillage	49.8	115	0.18^a	0.15	0.21	0.39	74.74	6.17
Conventional tillage	49.8	184	0.13^b	0.12	0.31	0.42	95.55	7.90
No-tillage	49.8	184	0.20^a	0.15	0.28	0.48	116.38	7.83
						K*; N*	T × N*	T*; N*

The number of ΔK^0 followed by the same letters are not different according to the non-differentiation test of the equation between conventional tillage and no-tillage; ΔK^0 – change of exchangeable potassium (Q); K_G – the coefficient of Gapon selectivity; Ks – K adsorbed in specific site; K_{ex}. – exchangeable K; K – potassium; N – nitrogen; T – tillage; *significant at $\alpha = 0.05$

K uptake by rice plants was not significant ($r = 0.33$), whereas the relationship between exchangeable K and K uptake by the plants was significant ($r = 0.73$*). Furthermore, the relationship between the exchangeable K in equilibrium (ΔK^0) and the potential buffer capacity of potassium (PBC_K) was significant ($r = 0.82$*), whereas the relationship between the potential buffer capacity of potassium (PBC_K) and the exchangeable K was not significant ($r = 0.29$). These results suggested that the role of the potential buffer capacity of potassium (PBC_K) in maintaining the availability of the K-labile is much greater than the role of PBC_K on exchangeable K.

Furthermore, Table 4 showed that the exchangeable K was positively correlated with AR_K ($r = 0.64$*) and ΔK^0 ($r = 0.59$*). This indicates that there was a relationship in the pattern of K supply for plants, both from the adsorbed K and the K-labile in the soil. In addition, there was a significant correlation between ARK and exchangeable K and K uptake ($r = 0.63$* and $r = 0.73$*, respectively), suggesting that K in equilibrium contributes to the pattern of K supply for rice plants.

There were significant relationships between the potential buffer capacity of potassium (PBC_K) and cation exchange capacity (CEC), and soil organic C ($r = 0.65$* and 0.70*, respectively) (Table 4). Evangelou et al. (1986) demonstrated the implications of the relationship between PBC_K and CEC, no-tillage and conventional tillage. They reported that in the no-tillage field, the accumulation of organic matter caused an increase in CEC. However, organic matter has a low affinity for monovalent cations such as K^+. The application of K fertiliser was not able to increase the soil potential buffer capacity of potassium (PBC_K) compared with the control (0 kg K/ha) (Table 2). This result is in accordance with the fact found by Sparks and Huang (1985) that the addition of K only slightly increased the PBC_K value; even the application of lime and fertiliser on subsoil could significantly decrease the PBC_K value. Furthermore, Table 2 also showed that increased rates of N fertiliser applied decreased the PBC_K value. The soils with low PBC_K value require more frequent K fertilisation, or K fertilisation should be given gradually. In other words, K fertiliser should be applied according to the plant growth phase, especially for rice; it should be given at 7 DAP and maximum tiller formation (approximately 21 DAP).

The present study showed that the application of no-tillage in lowland rice cultivation increased the yield of dry-milled grain by 9.96% compared with

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the application of conventional tillage (Table 3). The relationship between rice yield and Q/I K parameters is shown in Table 4. It can be seen that AR_K was significantly correlated with dry-milled grain yield (r = 0.75*). Meanwhile, there was a significant relationship between PBCK and K_G (r = 0.64*). Furthermore, the K-labile "pool" (ΔK^0) was significantly correlated with rice yield (r = 0.71*), indicating that K from the K-labile "pool" played a role in providing K in the soil, which was absorbed by plants to support grain yield.

In conclusion, our study suggested that the ratio of potassium activity (AR_K) and the potential buffer capacity of K (PBC_K) values in the tropical paddy soil under the no-tillage system were higher than those in the conventional tillage.

At the application of K fertiliser (49.8 kg K/ha), the implementation of no-tillage gave higher exchangeable K than the implementation of conventional tillage, indicating that the application of K fertiliser is more efficient in a no-tillage system. When the K fertiliser was added, the application of N fertiliser at the rate of 115 and 184 kg N/ha gave a higher AR_K value than the application of 46 kg N/ha, suggesting that simultaneous K and N fertiliser application was able to increase exchangeable K in the soil. Moreover, the ratio of K^+ activity in equilibrium was significantly correlated with K-uptake, indicating that the increase of the K-uptake was due to the increase of the available K in the soil.

The application of no-tillage increased the of dry grain yield (by about 10%) compared with the application of conventional tillage. Meanwhile, AR_K was significantly correlated with dry-milled grain yield. Furthermore, the K-labile (ΔK^0) was significantly correlated with rice yield, indicating that K from the K-labile pool played a role in providing K in the soil, which was absorbed by plants to support grain yield.

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