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Potassium release and fixation in old Brahmaputra and Ganges tidal floodplain soils of Bangladesh

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ABSTRACT

Plant availability of soil K is controlled by dynamic interactions among solution, exchangeable and nonexchangeable pools. Potassium (K^+) directly released from primary K-bearing minerals can contribute to plant nutrition. The objective of this research was to assess short-term K^+ release and fixation on Barisal silt (Barisal) and Chhiatasilty clay loam (BAU-Bangladesh Agricultural University) soils, which are intensively cropped with rice. Potassium sorption and desorption properties and the contributions of exchangeable K^+ (EK) and nonexchangeable K^+ (NEK) pools to K^+ dynamics of the soil-solution system was measured using a modified quantity-to-intensity (Q/I) experiment. The soil ability for K^+ release and fixation (β) for BAU and Barisal soil was 0.109 and 0.089, respectively. The equilibrium potential buffering capacity for exchangeable K^+ (PBC$_{\text{Exch}}$) derived from Q/I experiment was 48.41 for BAU soil and 65.24 for Barisal soil. The equilibrium potential buffering capacity for nonexchangeable K^+ (PBC$_{\text{Non-exch}}$) was 149.73 in BAU soil and 119.29 in Barisal soil, respectively. The BAU soil showed higher β value than the Barisal soil, indicating release and fixation of nonexchangeable K (NEK) would be greater in BAU soil than the Barisal soil. The amount of exchangeable K (EK) that was not in exchange equilibrium with Ca (E_{min}) in the experimental conditions was higher (0.114 cmol kg^{-1}) in Barisal soil than in BAU soil (0.049 cmol kg^{-1}). Equilibrium concentration ratio (CR$_0$) in Barisal soil was 0.807 (mmol L^{-1})$^{1/2}$ compared to 0.338 (mmol L^{-1})$^{1/2}$ in BAU soil. The equilibrium solution K (CK$_0$) was greater in Barisal soil 0.098 (mmol L^{-1})$^{1/2}$ than the BAU soil 0.039 (mmol L^{-1})$^{1/2}$. Estimated equilibrium exchangeable K (EK$_0$) for BAU and Barisal was 0.065 and 0.165 cmol kg^{-1}, respectively. Critical solution K (CK$_r$) value for Barisal soil was 0.103 mmol L^{-1}, which was greater than that of BAU soil (0.038 mmol L^{-1}). The calculated critical exchangeable K (EK$_r$) for BAU and Barisal soil was 0.049 and 0.109 cmol kg^{-1}, respectively. The value of EK$_r$ indicates that the release of nonexchangeable K would be initiated in BAU and Barisal soils when exchangeable K will be less than 0.049 and 0.109 cmol kg^{-1}, respectively. Potassium supplying parameters obtained from these K^+ release and fixation experiments would be useful for decision making in soil fertility management.

INTRODUCTION

Potassium (K+) as a nutrient element is essential for plant growth, and its role in agriculture is well recognized (Spark and Huang, 1985). The chemistry and fertility of K+ in soils of Bangladesh are scarcely studied because it has been thought soils in these regions contain large quantities of exchangeable K+ (EK) and non-exchangeable K+ (NEK). However, with increasing cropping intensities, high-yielding varieties, and the greater use of N and P fertilizers, the need for K+

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fertilizers is increasing (Rupta et al., 2003; Jalali, 2007).

Fertilizer use in Bangladesh is below optimum, and negative K+ balance indicated soil K+ mining (Ahsan et al., 1997), which makes soil K+ less readily available (Krauss, 1993, 1999). It was believed that most of the soils in Bangladesh contain sufficient EK (exchange with NH_4OAc) to support lowland rice in Bangladesh, because K responsive rice soils were only a few (Saleque et al., 1990). Introduction of high-yielding varieties and intensive cropping systems might have caused depletion of available K+ (Malakouti, 1999). In K deficient Barind soils, high yielding rice crop responded up to 120 kg K ha–1 (Saleque et al., 1998).

The dissolution of K+ fertilizers releases K+ into the soil solution but most of this K+ is rapidly transferred to the EK, and some may become NEK (Johnston and Goulding, 1990). Fertilization-recommendation systems for K+ involve soil analyses, which are generally based on several chemical extraction methodologies (Schneider et al., 2003). The relationship between different soil-extraction methods to predict K+ release from soil was studied in 19 field experiments on a range of mineral soil types in Norway by Øgaard and Krogstad (2005b). They found that 0.1 M and 0.5 M HNO_3–extractable K+ were better predictors of K+ uptake than 2M HCl–extractable K+. For K+, available soil K+ is determined largely by extraction with neutral 1M ammonium acetate (NH_4OAc) or similar extractants, which extract mainly solution and EK (Mengel et al., 1998).

Minimal exchangeable K+ (Emin) is a fraction of EK retained by the soil and would not exchange with calcium (Ca^{2+}) in the soil solution, despite their extraction with NH_4OAc. Schneider (1997a, b) indicated that when EK is close to Emin, it is meaningless to use EK as a soil fertility indicator.

Non-exchangeable K+ is a source of K+ in some soils and can be released to provide a significant portion of the K+ removed by crops during the growing season (Mengel and Uhlenbecker, 1993; Rahmatulla et al., 1994). Øgaard and Krogstad (2005a) studied K+ release in Norwegian soils. The soils used were noncalcareous, had a high content of organic matter (OM) and low clay content, and illite was the most common mineral in the soils. Jalali and Zarabi (2006) studied kinetics of K+ release and wheat uptake in a greenhouse experiment in some calcareous soils. They found that the rate of K+ released to 0.01 M $CaCl_2$ was correlated with cumulative K+ uptake. They concluded that a fraction of non-exchangeable K+ was taken up by wheat. Several attempts have been proposed to characterize the capacity of total available K+ by extracting a fraction of NEK (Richards and Bates, 1988).

Recent work has suggested that EK, NEK, and clay mineralogy should be considered together when making fertilizer recommendations (Ghosh and Singh, 2001). Several researchers (Beckett, 1964; Sparks and Huang, 1985; Evangelou et al., 1994; Nair, 1996) suggested that quantity-to-intensity (Q: I) relationship can be used to describe the status of K+ using the relationship between intensity and capacity of soil K+ or soil K+ buffering characteristics. At a given time, release and fixation can occur during the source of the Q: I experiments (Schneider, 1997a, b). Datta and Sastry (1988) reported that analyzing the EK at the end of the contact between soil and solution can be used to determine the threshold K+ concentration in solution and EK below which release of NEK is initiated. Schneider (1997a) and Wang et al. (2004) adapted DattaSastry's method to quantify the contribution of EK and NEK to the overall K+ balance of soil-solution system and measure fixation and release of K+ during sorption and desorption. Therefore, research on the K+ supplying power and release of NEK may give a better understanding of their K+ status. However, studies on K supplying characteristics and K dynamics parameters for the soils of Bangladesh received scanty attention.

Anisuzzaman (2005) studied Q/I relationship for some soils of the Ganges river floodplain. Soils of the Ganges tidal floodplain and Old Brahmaputra floodplain covered an extensive area for rice cultivation and the different in mineralogical make up (Moslehuddin and Egashira, 1999). The present investigation was aimed to compare K+ chemistry of Old Brahmaputra Floodplain (BAU-Bangladesh Agricultural University) and Ganges Tidal Floodplain (Barisal) soils characteristics for water soluble, exchangeable and nonexchangeable K with determination of Q/I relationship of K and changes of K in the soil-solution system into exchangeable and nonexchangeable pools in BAU and Barisal soils.

MATERIALS AND METHODS

Laboratory experiments were carried out at Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh with a view to examining the potassium status and availability index of Old Brahmaputra Floodplain (BAU) and Ganges Tidal Floodplain (Barisal) soils of Bangladesh.

Collection and preparation of soil samples

Old Brahmaputra Floodplainsoil was collected from Bangladesh Agricultural University, Mymensingh, Farm,and Bangladesh Rice Research Institute Regional Station Farm, Sagardi, Barisal. Both the soils were collected from fields. Soils samples were collected from 0 – 15 cm depth from a selected field that had been cropped to rice from 10 points. The samples were composited, air-dried, crushed and passed through a 2-mm sieve and potted for study.

Determination of soil characteristics

Soil pH was determined by using glass electrode method (Peech, 1965). Soil texture was determined by hydrometer method (Chapman, 1965). Organic carbon was determined by Walkley and Black wet digestion method (Nelson and Sommers, 1982).Cation Exchange Capacity (CEC) of soil was determined by Na saturation method as outlined by Rhodes (1982).

Solution and exchangeable K, Ca, Mg and Na were measured by atomic absorption spectrophotometer. Non- exchangeable K was measured by Flame photometer by Flame photometer for total K.The mineral K was estimated by subtracting solution, exchangeable and nonexchangeable K from total K. as, Mineral K = Total K- (solution K+ exchangeable K+ nonexchangeable K). All measurements were done in triplicate.

The release pattern of K with $CaCl_2$ (0.01M) and release pattern of K with 1.0 M NH_4OAc in soil samples were determined according to the protocol described elsewhere.

Effect of water logging on potassium release

One hundred g of soil sample was incubated with two K levels and two water regimes, therefore, there was a 2 × 2 × 2 factorial experiment. The factors of the experiment were as follows:

- Soil 2: (1) BAU and (2) Barisal soil
- Potassium levels 2: no K (K_0) and 100 mg K/kg soil (K_{100})
- Water regime 2: aerobic and anaerobic

The measured amount of soil sample was taken in a polythene bag and 10 ml KCl (1.91 g L^{-1}) solution was added for K_{100} treatment and only 10 ml distilled water was added to the K_0 treatment. After adding KCl or water, the polythene bag was left over night to soak the solution/water, which formed a wet lump of soil. Then the lump was mixed smoothly but thoroughly through gentle rubbing of the bag without touching the sample directly.

For aerobic treatment, 2.5 g portion of the mixed sample was taken 50 ml centrifuge tube and for anaerobic treatment the same amount of soil was taken in similar tube containing 10 ml de-oxidized water. De-oxidized water was prepared by boiling distilled water for two hours followed by cooling it overnight. The sample was incubated for six weeks in duplicate.

At each week, 30 ml 1.0 M NH_4OAc was added to the tubes of aerobic treatment and 20 ml NH_4OAc (115.5 g L^{-1}) was added to the anaerobic samples, which resulted the concentration of NH_4OAc to 1.0 M with the previous 10 ml water. The sample was shaken for 30 minutes, filtered through Whatman # 42 measured available K by flame photometer.

Quantity-Intensity (Q/I) relationships for potassium of soils

Potassium Q/I isotherms were constructed according to the modified procedureof Beckett (1964) described by Wang et al. (2004).

Regression analysis was done by MS Excel software and statistical analysis was done in IRRISTAT software.

RESULTS AND DISCUSSION

Soil characteristics

The Old Brahmaputra floodplain (BAU) and Ganges tidal floodplain (Barisal) soils differed widely by their pH, texture, CEC, K status and K saturation (Table 1). In BAU and Barisal soils pH were 6.31± 0.01 and 6.03 ± 0.01; BAU soil contained 31% sand, 37% silt and 32% clay, while Barisal soil has 2% sand, 73% silt and 25% clay. Organic carbon content in BAU and Barisal soil were 1.13 and 1.19 %. Barisal soil had higher CEC than BAU. The exchangeable K in BAU and Barisal soils were 0.07 and 0.20 meq/100g soil, exchangeable Ca were 9.54 and 15.00 meq/100 g, exchangeable Mg were 2.03 and 2.48 meq/100g soil, and exchangeable Na in both the soils was 0.14 meq/100g soil, respectively. Potassium saturation was 0.59% in BAU soil and 1.12% in Barisal soil. Potassium saturation is used to characterize the K^+ status of soils(Schneider and Villemin, 1992). Soil test results show that the BAU soil was deficient in K, while Barisal soil contained exchangeable K above the critical level (Saleque et al., 1990). According to the basic cation saturation ratio (BCSR) both the soils showed K saturation of less than 2, therefore, both of them are expected to be K deficient (McLean, 1976). However, Kopittke and Menzies (2007) disproved the BCSR concept.

Potassium forms

Total K in BAU soil was 10.69 meq/100 g soil, while that in Barisal soil was 14.49 meq/100g (Table 2). Solution K content in two soils were 19 and 45 ppm, which was 0.46% of the total K in case BAU and 0.80% of total K in Barisal soil. The solution K represents 70 and 58% of the exchangeable K in BAU and Barisal soil, respectively. Exchangeable K content in BAU soil was 0.07 meq/100 g, while that in Barisal soil was 0.20 meq/100 g. The exchangeable K was 0.65 and 1.38% of total K, 41 and 65% of nonexchangeable K in BAU and Barisal soil, respectively. Nonexchangeable K in BAU and Barisal soil was 0.17 and 0.31 meq/100 g, which constituted 1.6 and 2.1% of total K in BAU and Barisal soil, respectively. In both the soils mineral K was the dominant fraction that constituted 98 and 97% of total K in BAU and Barisal soils, respectively. Hombunaka and Rowell (2002) indicated that the levels of exchangeable K reflect the ability of the soil minerals to weather and release of K^+. The release of interlayer K^+ increases when the concentrations of soil solution K^+ and / or exchangeable K^+ decrease due to K^+ uptake by plants and leaching (Hinsinger and Jaillard, 1993; Øgaard and Krogstad, 2005). The silicate weathering in the carbonate-containing soils may not be important, and there may be some K^+ release by ion exchange of interlayer K^+ with hydrated cations, such as $Ca^{2+}$and Mg^{2+}.

Table 1: Physical and chemical properties of two soils used for potassium chemistry studies.

Characteristics	BAU soil	Barisal soil
Sand (%)	31 ± 3	2 ± 1
Silt (%)	37 ± 2	73 ± 1
Clay (%)	32 ± 2	25 ± 0
Texture	Silty clay loam	silt
pH	6.31 ± 0.01	6.03 ± 0.01
Organic C (%)	1.13 ± 0.00	1.19 ± 0.01
CEC (meq/100 g soil)	15.13 ± 0.26	22.47 ±0.13
Exch. K (meq/100 g soil)	0.07 ± 0	0.20 ± 0
Exch. Ca (meq/100 g soil)	9.54 ± 0.5	15.00 ± 0
Exch. Mg (meq/100 g soil)	2.03 ± 0.04	2.48 ± 0.03
Exch. Na (meq/100 g soil)	0.14 ± 0.00	0.14 ± 0.00
K saturation (%)	0.59	1.12

Table 2: Forms of potassium in Old Brahmaputra flooplain (BAU) and Ganges tidal floodplain (Barisal) soils.

Characteristics	BAU soil	Barisal soil
Solution K (ppm)	19 ± 0	45 ±0
Exchangeable K (meq/100 g soil)	0.07 ± 0	0.20 ± 0
Nonexchangeable K (meq/100 g soil)	0.17 ± 0.00	0.31 ± 0.01
Mineral K (meq/100 g soil)	10.44	13.99
Total K (meq/100 g soil)	10.69 ± 0.89	14.49 ± 0.72

Release pattern of K with 0.01M $CaCl_2$

Potassium release due to repeated extraction with 0.01 M $CaCl_2$ solution was higher from Barisal soil than BAU soil (Fig.1A). The release of K in the first day extraction of BAU soil was 34 mg/kg while in Barisal soil was 70 mg/kg. In the subsequent extractions, the magnitude of K release decreased progressively. In the 2nd day extraction the released K in BAU soil was 10 mg/kg that in Barisal soil was 31 mg/kg. In third extraction, Barisal and BAU soil yielded 12 and 2 mg/kg, respectively, while in fourth extraction K release in Barisal soil was 5 mg/kg but in BAU soil it was trace. Barisal soil released minute amount of K up to 8th day of extraction. The cumulative potassium release was higher in Barisal soil than the BAU soil (Fig. 1B). Cumulative solution K in Barisal soil 126 mg/kg, while that in BAU soil it was only 47 mg/kg. The cumulative potassium release increased up to eighth extraction in case of Barisal soil while in the BAU soil it increased up to third extraction.

Release pattern of K with 1.0M NH_4OAC

Potassium release due to repeated extraction with 1.0 M NH_4OAc solution was higher from Barisal soil than BAU soil (Fig.1C). The release pattern of K from first day extraction in BAU soil was 56 mg/kg while in Barisal soil was 138 mg/kg. In the subsequent extractions, the magnitude of K release decreased progressively. In the second extraction the released K in BAU soil was 8 mg/kg but that in Barisal soil was 18 mg/kg. The release K was sharply falling from the first extraction to the second extraction in both soils due to repeated extraction with 1M NH_4OAC solution. In the third extraction K release in Barisal soil was 4 mg/kg but in BAU soil it was 0.8 mg/kg. In the 4th day extraction the released K from both soils became zero. The cumulative potassium release was higher in Barisal soil than theBAU soil (Fig.1D).

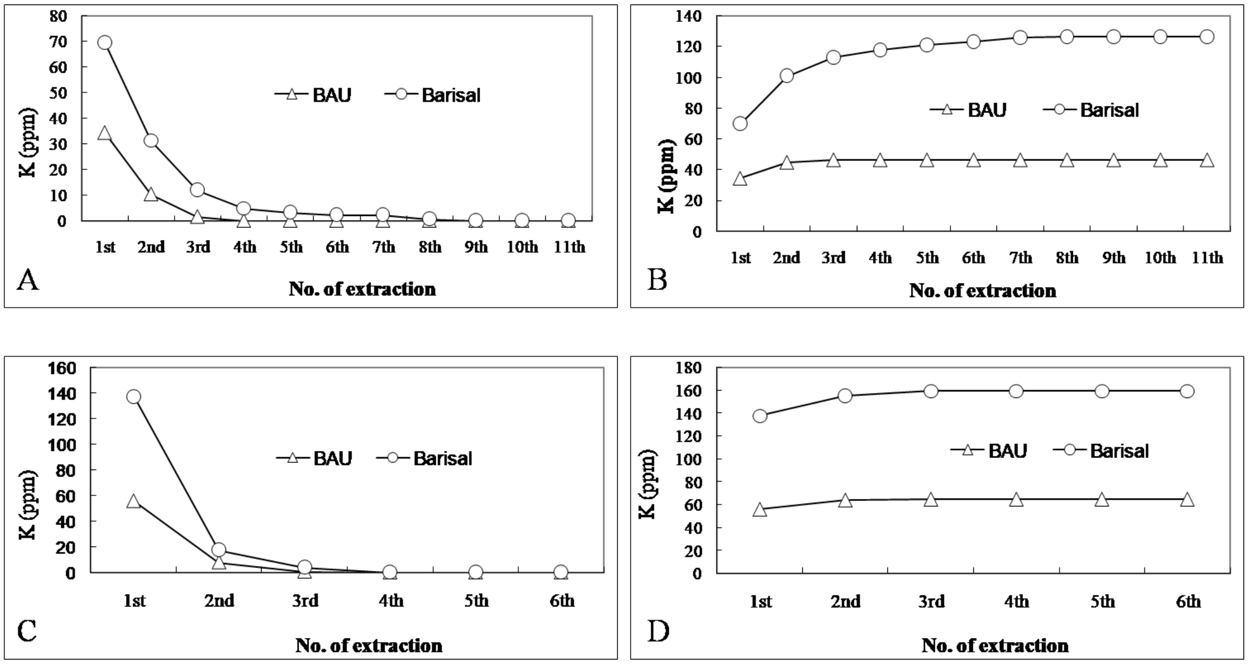

Figure 1: Potassium (mg/kg) release (A) and cumulative potassium (mg/kg) release (B) from BAU and Sagardi soils due to repeated extraction with 0.01 M $CaCl_2$ solution. Potassium (mg/kg) release (C) and cumulative potassium (mg/kg) release (D) from BAU and Sagardi soils due to repeated extraction with 1.0 M NH_4OAC solution.

Effect of waterlogging on potassium release under aerobic and anaerobic conditions

Table 3 shows that the interaction of soil (S) × moisture regime (M) × potassium level (K) was significant only at the second week after incubation (p = 0.030). Main effect of soil and K was significant (p = 0.000), but moisture regime was significant at all the weeks after incubation except first (p = 0.565). The interaction of S × M was significant only at the second week (p=0.030), while S × K was significant in all weeks after incubation (p = 0.018, 0.017, 0.001, 0.000, 0.000, 0.000, respectively) and M × K was significant in all weeks after incubation except in first week (p=0.624).

Initially, the available K content in BAU soil was 45 (mg/kg), which increased to 108 mg/kg with the application of 100 mg K/kg soil (K_0). Incubation of soil under waterlogging condition increased available K both in K-control (K_0) and K_{100} treatments (Fig.2). The magnitude of increase in available K due to waterlogging was higher in K_{100} than K_0. Waterlogging increased available K in K_0, only by 5 ppm after one week of incubation, 7 ppm after two weeks, but after three weeks it fell to 4 ppm. Available K increases due to waterlogging after four and five weeks of incubation was 13 and 11 ppm, respectively. Receiving 100 ppm K application (K_{100}), BAU soil showed 89 ppm available K under air-dry condition and 100 under waterlogging condition prior to incubation. Incubation of soil both under waterlogging and without waterlogging decreased available K content up to three weeks of incubation (Fig. 2). At fourth and fifth week of incubation the available K content was increased both under aerobic and waterlogging conditions. Waterlogging of K_{100} soil increased available K by 12 ppm after 1 week of incubation, but the magnitude was 30 ppm after 2, 3, and 5 weeks of incubation, however, it was 48 ppm after 4 weeks of incubation.

The recovery (%) of applied K (by NH_4OAc extraction) was 43, 32, 10, 13, 14 and 25% from initial to fifth week of incubation, respectively under air-dry condition and 54, 40, 32, 40, 49 and 44% from initial to fifth week of incubation, respectively, under waterlogging condition (Table 4). Waterlogging condition released more available K than the air-dry condition. The magnitude of increase in native available K due to waterlogging in BAU soil was too low to support rice plant growth without K application. However, the motion of increase in K availability due to waterlogging can't be ignored.

Table 3: F-probability analysis for potassium release under two moisture regimes and two potassium levels as affected by different period of incubation.

		F-probability at different week of incubation					
Sources of variation	df	Initial	First	Second	Third	Fourth	Fifth
Soil (S)	1	0.000	0.000	0.000	0.000	0.000	0.000
Moisture levels (M)	1	0.013	0.565	0.000	0.000	0.000	0.000
Potassium levels (K)	1	0.000	0.000	0.000	0.000	0.000	0.000
S × M	1	0.089	0.059	0.030	0.056	0.877	0.782
S × K	1	0.018	0.017	0.001	0.000	0.000	0.000
M × K	1	0.037	0.624	0.001	0.000	0.000	0.011
S × M × K	1	0.178	0.268	0.078	0.176	0.205	0.782
Residual	8						
CV (%)		9.4	9.5	7	4.5	3.4	5

Table 4: Recovery (%) of applied K by NH_4OAc extraction at different time of incubation under aerobic and waterlogging conditions.

	Week after submergence					
	Initial	First	Second	Third	Fourth	Fifth
	BAU soil					
Air-dry condition	43	32	10	13	14	25
Waterlogged	54	40	32	40	49	44
	Barisal soil					
Air-dry condition	59	77	35	55	61	89
Waterlogged	101	59	89	96	107	112

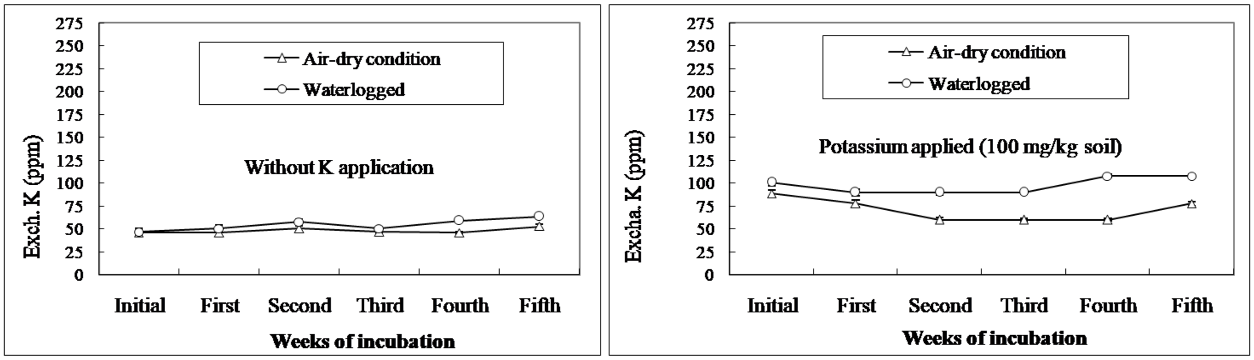

Figure 2: Effect of K application and different period of waterlogging on exchangeable K concentration in BAU soil.

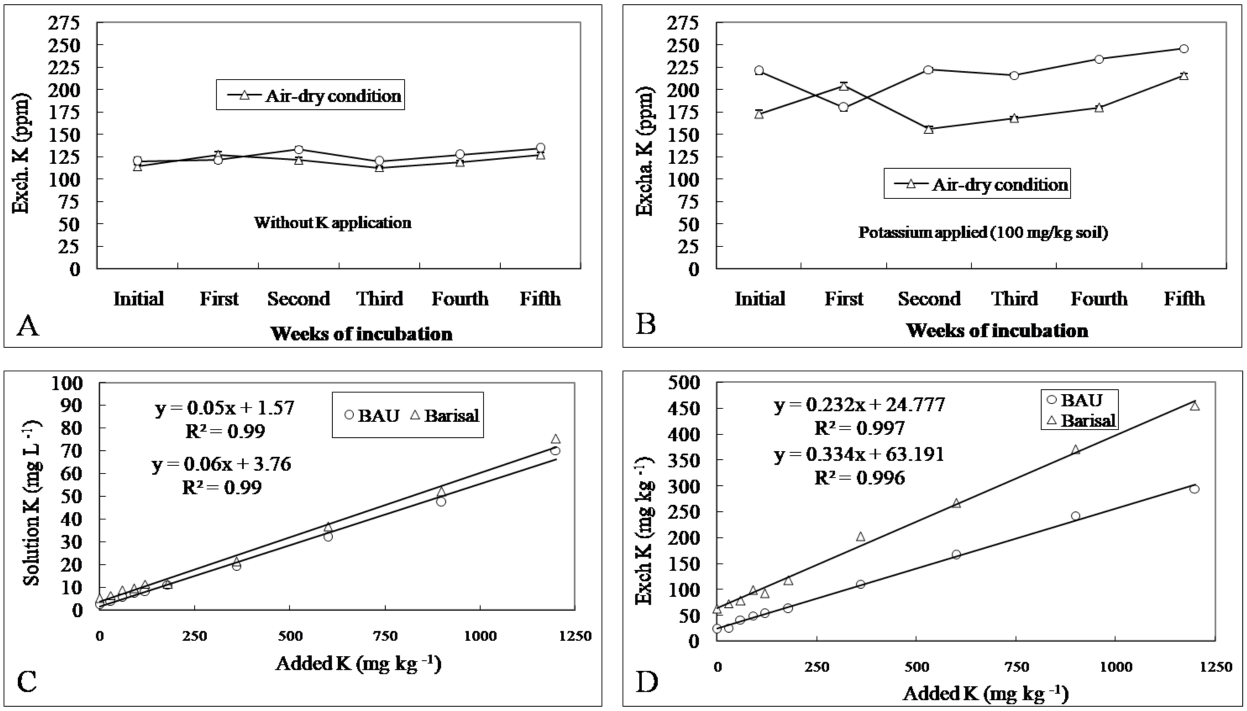

Figure 3: A.B. Effect of K application and different period of waterlogging on exchangeable K concentration in Barisal soil. C. Relationship between added K and solution K for BAU and Barisal soils. D. Relationship between added K and exchangeable K for BAU and Barisal soils.

Native available K content (K_0) in Barisal soil was 114 ppm under aerobic condition and 120 ppm under waterlogging condition prior to incubation, receiving 100 ppm K application it increased to 173 and 221 ppm under aerobic and waterlogging conditions, respectively. Waterlogging decreased available K in both K_0 and K_{100} treatments after 1 week of incubation, but it increased available K when incubation period was 2 weeks or more (Fig. 3AB). Incubation of K_0 soil showed that waterlogging increased available K by 12 ppm after 2 weeks of incubation, but after 3, 4 and 5 weeks of incubation the magnitude of available K increase was 7-8 ppm. In K_{100} soil of Barisal waterlogging increased 66 ppm after 2 week of incubation, 48 ppm after 3 weeks, 54 ppm after 4 weeks and 30 ppm after 5 weeks of incubation.

The recovery of applied K (by NH_4OAc extraction) was 59, 77, 35, 55, 61 and 89% from initial to fifth week of incubation respectively under air-dry condition and 101, 59, 89, 96, 107, and 112% respectively, under waterlogging condition (Table 4). Recovery of applied K in Barisal soil was higher than BAU soil.

Effect of K application on solution K and exchangeable K

Application of K to soil increased solution K in both tested soils (Fig.3C). Relationship between added K was linear (R^2 = 0.99 in both soils). It means that the simple linear regression equation ($y = 0.05x + 1.57$ for BAU soil and $y = 0.06x + 3.76$ for Barisal soil) can explain 99% of the relationship. The increase in solution K due to added K was higher in Barisal soil than that of BAU soil. The intercept of solution K of BAU soil was 1.57 while that of Barisal soil was 3.76. The slope of regression line in BAU soil was 0.05 and that in Barisal soil was 0.06. It means application of 1mg K/kg soil brought an increase in solution K of 0.05mg K/kg in BAU soil and 0.06mg K/kg in Barisal soil.

The application of K to soil increased exchangeable K in both tested soils (Fig.3D). Relationship between added K and exchangeable K was linear (In BAU soil R^2 = 0.997 and in Barisal soil R^2 = 0.996). The increase in exchangeable K due to added K was higher in Barisal soil than that of BAU soil. The slope of regression line in BAU soil was 0.2317 and that in Barisal soil was 0.3343. It means application of 1mg K/kg soil brought an increase in exchangeable K of 0.23 and 0.33 ppm in BAU soil Barisal soil. The intercept for BAU and Barisal soils was 24.77 and 63.19, respectively.

Quantity-to-intensity relationships

Results of partitioned Q/I curves for the Old Brahmaputra floodplain (BAU) and Ganges tidal floodplain (Barisal) soils are presented in Fig. 9 and Fig. 10. In both the BAU and Barisal soils, the relationship of concentration ratio (CR) with the total change in K (ΔK_{Total}), change in exchangeable K (ΔK_{Exch}), and nonexchangeable K (ΔK_{NE}) was curvilinear (R^2 = 0.99). The intercept for ΔK_{Total}, ΔK_{Exch}, and ΔK_{NE} in BAU soil was 0.141, 0.056 and 0.086, respectively, while that in Barisal soil was 0.207, 0.016 and 0.191, respectively. In both BAU and Barisal soils, intercept for ΔK_{NE} was higher than the ΔK_{Exch}.

The Q: I plot shows a linear relationship at high concentration ratios and curvilinear at low intensity levels (Jimenenzand Para, 1991; Schneider et al., 2003). Traditional Q/I curves have termed “immediate” relations of the labile K pool, K fixation was often suspected to happen when longer soil solution contacts were used (Beckett, 1964). The partition of Q/I curve was allowed to explicitly assess K changes associated with slowly available or nonexchangeable K. The amount of total K adsorbed or released (ΔK) during the experiment was partitioned into changes due to exchangeable K and nonexchangeable K. The changes due to exchangeable K was measured by re-extracting the amount of K at end of soil $CaCl_2$ contact with 1 M NH_4OAc and by correcting for remaining interstitial solution K. The change due to nonexchangeable K was calculated by difference between total amount K adsorbed and the amount K re-extracted by NH_4OAc. This change in nonexchangeable K is considered as short term fixed K (Schneider, 1997).

In BAU soil, when concentration ratio (CR) was <0.33 $(mmolL^{-1})^{1/2}$ then it starts desorption in case of exchangeable K. Similarly in case of nonexchangeable and total K when concentration ratio (CR) <0.34 $(\text{mmolL}^{-1})^{1/2}$, <0.35 $(\text{mmolL}^{-1})^{1/2}$ respectively then desorption was started. In Barisal soil, when CR <0.78 $(\text{mmolL}^{-1})^{1/2}$ then it starts desorption while (CR)<0.81$(\text{mmolL}^{-1})^{1/2}$ and <0.81 $(\text{mmolL}^{-1})^{1/2}$ for nonexchangeable and total K desorption was started. Both the BAU and Barisal soil showed strong total adsorption of K as solution CR increased (Fig. 4A and Fig. 4B). The quantity of ΔK due to exchangeable pools was less than that due to nonexchangeable pools for both soils. The Barisal soil released relatively more K from its nonexchangeable fractions than from exchangeable sites than BAU soil.

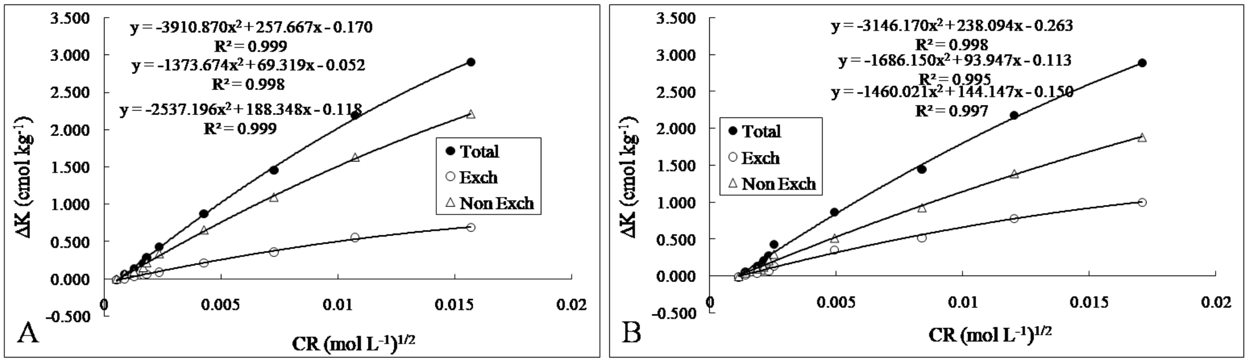

Figure 4 A. Q/I relationship for BAU soil. B. Q/I relationship for Barisal soil.

Table 5: Some characteristic values of K^+ dynamics in the soil-solution system of the Old Brahmaputra floodplain (BAU) and Ganges tidal floodplain (Barisal) soils.

Characteristics value of potassium dynamics	BAU soil	Barisal soil
Equilibrium concentration ratio, CR_0, $(\text{mmol L}^{-1})^{1/2}$	0.338	0.807
Equilibrium solution K, CK_0 (mmol L^{-1})	0.039	0.098
Equilibrium exchangeable K, EK_0 (cmol kg^{-1})	0.065	0.165
Minimum exchangeable K, $E_{min}$$(\text{cmol kg}^{-1})$	0.049	0.114
Critical solution K, CK_r (mmol L^{-1})	0.038	0.103
Critical exchangeable K, EK_r (cmol kg^{-1})	0.049	0.109
PBC_{Exch}	48.41 ± 2.09	65.24 ± 2.91
$PBC_{Non\text{-}exch}$	149.73 ± 3.89	119.29 ± 3.19
PBC_{Total}	198.14 ± 5.81	184.53 ± 5.56
Proportion of applied K to exchangeable K, α	0.25 ± 0.004	0.35 ± 0.008
Proportion of applied K to nonexchangeable K, β	0.109± 0.003	0.089 ± 0.003

Equilibrium concentration ratio (CR_0)

Equilibrium concentration ratio (CR_0), a measure of K intensity in the soil-$CaCl_2$ system, was estimated from least squares regression equations that described partitioned Q/I curves (Fig. 4A andFig.4B). The CR_0 value corresponds to the system solution CR at which $\Delta K = 0$ (no adsorption and desorption). The higher CR_0 was in Barisal soil 0.807 $(\text{mmol L}^{-1})^{1/2}$, which was higher than BAU soil CR_0 0.338 $(\text{mmol L}^{-1})^{1/2}$ (Table 5). Wang et al. (2004) reported CR_0 of 4, 5 and 10 $(\text{mmol L}^{-1})^{1/2}$ for three American soils. The CR_0 value in each soil decreased with the increasing depth. In the calcareous soils of Iran the CR_0 varied from 0.9 to 15.1 $(\text{mmol L}^{-1})^{1/2}$ (Jalali and Kolachi, 2007).

The magnitude of CR_0 gives an indication of the type of exchange sites involved in reaction (Barbayiannis et al, 1996).Values of CR_0 <0.001 $(\text{mol L}^{-1})^{1/2}$ indicate that K^+ is absorbed at high-affinity (edge positions) sites, and if the values are >0.01 $(\text{mol L}^{-1})^{1/2}$, K^+ is adsorbed on planar sites (Sparks and Liebhardt, 1981).

Potential buffering capacity

Potential buffering capacity (PBC), an indicator of soil's buffering ability, was estimated from the slope of the linear regression between CR and ΔK (Fig. 4A and Fig. 4B). The two soils exhibited different K buffering capacities. The PBC$_{\mathrm{Exch}}$, PBC$_{\mathrm{Non\text{-}exch}}$ and PBC$_{\mathrm{Total}}$ was 48.41 ± 2.09, 149.73 ± 3.89 and 149.73 ± 3.89 in BAU soil and 65.24 ± 2.91, 119.29 ± 3.19 and 184.53 ± 5.56 in Barisal soil, respectively (Table 5). Le Roux and Sumner (1968) observed a high PBC in K^+-depleted soils by continues cropping and also indicated that such increases in PBC will be most marked in soils having mica as the dominant mineral as a result of its preference for K^+ especially at very low exchangeable K^+ saturation. Potassium saturation was comparatively low in BAU soil than the Barisal soil. Since soils exhibiting high K-affinity sites are high in K^+ fixation capacity (Rich, 1968; Aideet al., 1999), clay mineralogical differences and factors affecting NEK dynamics may be the key in controlling PBC differences in soils (Wang et al., 2004). Ruptaet al. (2003) reported PBC of 111 and 137 in Inceptisol and Vertisol, respectively. The relationship between EK_f (final exchangeable K^+) and CR (K^+ concentration ratio) was curvilinear (Fig. 5A) in BAU soil, R^2= 0.998 and in Barisal soil, R^2= 0.995. The EK_f was higher in Barisal soil than the BAU soil. The intercept of the BAU soil was 0.013 while that of Barisal soil was 0.052.

The critical CR was calculated from the linear relationship (Fig. not shown). The slope for the BAU soil was 48.41 and in Barisal soil was 65.24. The critical CR was 0.001 $(\mathrm{molL}^{-1})^{1/2}$ for BAU soil and in Barisal soil it was CR 0.0017 $(\mathrm{molL}^{-1})^{1/2}$. It means the BAU soil would start to desorb K when CR would < 0.001 $(\mathrm{molL}^{-1})^{1/2}$ and this value for Barisal soil should be 0.0017 $(\mathrm{molL}^{-1})^{1/2}$.

Equilibrium exchangeable K (EK_0)

The relationship between EK_f and △K is illustrated in Fig. 5B. Simple linear regression equation explained the relationship between EK_f and △K (R^2 = 0.997 for BAU soil and R^2= 0.996 for Barisal soil). The corresponding values of EK_fat △K = 0 for which neither sorption nor desorption occur (EK_0) was calculated from the regression equations of Fig. 5B. Estimated EK_0 for BAU and Barisal was 0.065 and 0.165 cmol kg^{-1}, respectively (Table 5). Wang et al. (2004) reported EK_0 values of 0.22 – 0.26 cmol kg^{-1} for three American soils. They reported that EK_0 in soils of deeper horizons was lower than that of upper horizon. At 30 – 45 cm soil depth, the EK_0 was 0.14 cmol kg^{-1} in Norwood silt loam soil. In some calcareous soils of Iran Jalali and Kolachi (2007) reported EK_0 in the range of 0.183 – 1.60 cmol kg^{-1}. Ganges tidal floodplain and Old Brahmaputra flood plain soils of Bangladesh showed much lower EK_0 than the reported American and Iranian soils. However, EK_0 for many of the soils of Bangladesh are yet to be determined.

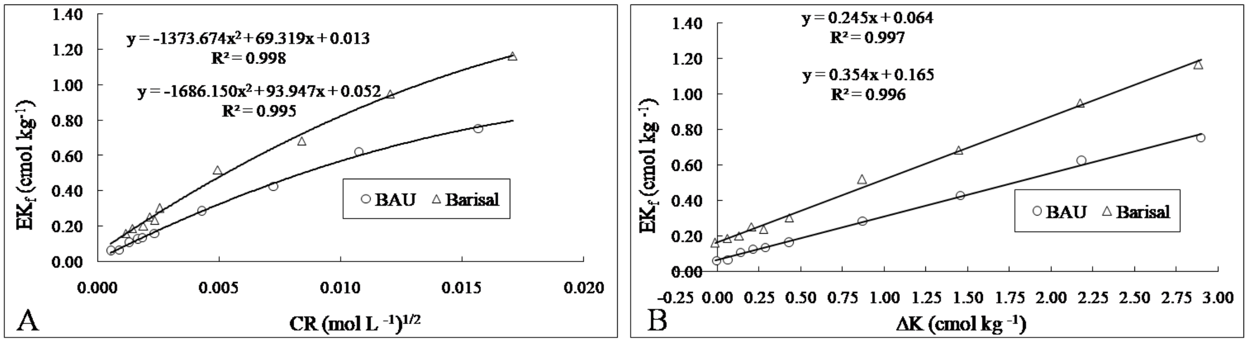

Figure 5 A. Relationship between final exchangeable K^+ and K^+ concentration ratio of the soil solution in BAU and Barisal soils.B. Final exchangeable K^+ as a function of the change in the exchangeable K^+ in BAU and Barisal soils.

Conversion of added K to exchangeable K

Proportion of the added K to be converted to the exchangeable K can be calculated from the slope of the regression line between $EK_f$and △K (Wang et al., 2004). Both the BAU and Barisal soils showed linear relationship between $EK_f$and △K (Fig. 5B). Coefficient of determination (R^2) of the linear regression for Barisal soil was 0.996 and that for BAU soil was 0.997. Slope of the regression line for BAU soil was 0.245 and that for Barisal soil was 0.354. The factor of conversion of added K to exchangeable K is defined as α, essentially slope of the regression line. The α for the BAU soil was 0.245 and that in Barisal soil was 0.354. JalaliandKolahchi (2007) reported αvalues for 14 soils of Iran in a range from 0.545 to 0.817. Wang et al (2004) reported αvalues of Crowley silt loam, Dundee silt loam and Norwood silt loam of surface and subsurface soils, which exhibited 0.44 to 0.60 and 0.17 to 0.62, respectively.

Relationship between K saturation ratio (SR_K) and cation exchange capacity (CEC)

Figure6A represents the relationship between K saturation ratio (SR_K) and cation exchange capacity. In both the soils the relationship between SR_K and CEC was linear (for BAU soil R^2 = 0.98 and for Barisal soil R^2 = 0.99). The intercept of BAU and Barisal soil was 0.51 and 0.32, respectively. In BAU soil the slope of the regression line was 290.33 that in Barisal soil was 319.95.The exchange affinity for K^+ (relatively to Ca^{2+} and Mg^{2+}) of a soil (slope of the SR_K vs. CR_f) also depends on the content and properties of the exchange materials present in the soil (Schneider et al., 2003). Thus, when compared to other soils having a similar K^+ buffer power; these soils must present a greater SR_K value to reach a similar CR_fvalue (Schneideret al., 2003).

Equilibrium solution K (CK_0)

The relation between △Exchangeable K and CK_f is presented in Fig.6B. The relationship between △K and K^+ concentration (CK_f) in soil solution BAU and Barisal soil was linear (Fig.14); R^2=0.994 and 0.987 in BAU and Barisal soil, respectively. The intercept of the regression line in BAU and Barisal soil was 0.068 and 0.161, respectively. The slope of BAU soil was 1738.26, while that of Barisal soil was 1650.71. CK_0 (0.039 mmol L^{-1}) in BAU soil and (0.098mmol L^{-1}) in Barisal soil was found. The intersection of the curves with the abscissa defines the initial K^+ concentration in solution for which neither sorption nor desorption would occur (CK_0).

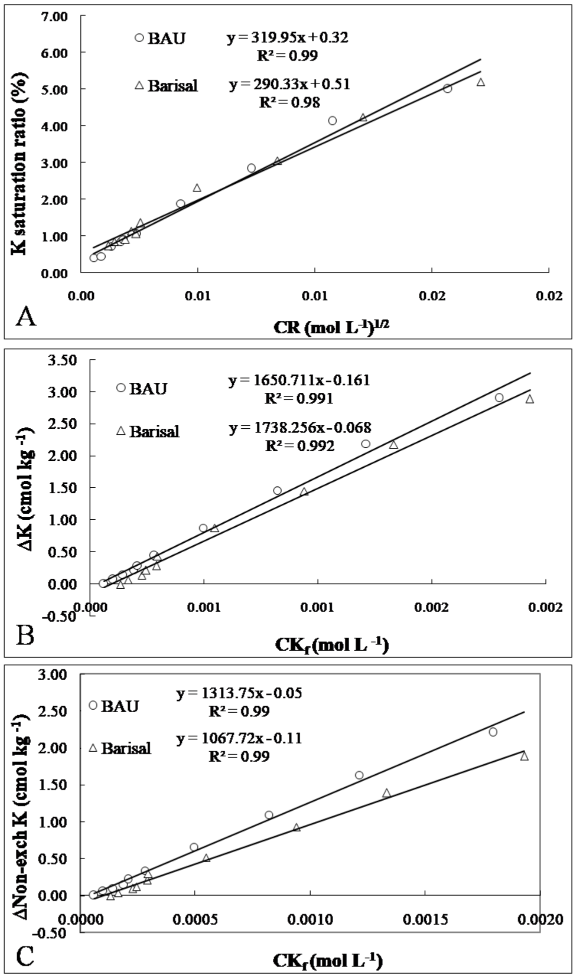

Figure 6 A. Relationship between K saturation ratio of the CEC and K concentration ratio in BAU and Barisal soils. B. Relationship between DK and K^+ concentration in soil solution in BAU and Barisal soils. C. Relationship between equilibrium K concentration in soil solution and DNon-ecxh K(cmol kg^1) in BAU and Barisal soils.

Critical value of solution K (CK_r) for nonexchangeable K release

There was linear relationship between equilibrium K concentrations (CK_f) in soil solution and change in nonexchangeable K (△NEK) in BAU and Barisal soil (6C). The intercept of the linear regression equation for BAU and Barisal soil was 0.05 and 0.18, respectively, and the slope of regression line for BAU soil was 998.62 while that for Barisal soil was 608.03. The contribution of NEK to the balance in the soil-solution system was assessed using data points showing total net nonexchangeable K^+ release against CK_f. Critical value of solution K^+ (CK_r) for nonexchangeable K release was calculated from the regression equations of Fig. 6C (Datta and Sastry, 1988).

$CK_r$is the critical value of CK_f at which △NEK = 0, below which the release of NEK is initiated. CK_r can be obtained by dividing the intercept by slope of the regression equation of △NEK (in the *y*-axis) and CK_f (*x*-axis). Estimated CK_r value for Barisal soil was 0.103 mmol L^{-1}, which was greater than that of BAU soil (0.038 mmol L^{-1}). This may indicated that a smaller depletion of solution K^+ would be needed by Barisal soil than BAU soil for initiation of NEK release. Jalali and Kolachi (2007) reported CK_r in the range of 0.09 – 1.32 mmol L^{-1} for some calcareous soils of Iran.

Critical Exchangeable K (EK_r) and minimum exchangeable K (E_{min})

The relationship between EK_f and CK_f was linear (Fig. 7). In the BAU soil, the linear regression between EK_f and CK_f was $y = 424.505x + 0.049$, $R^2 = 0.984$, while that for Barisal soil was $y = 582.996x + 0.109$, $R^2 = 0.980$. Critical exchangeable K (EK_r) was obtained by interpolation from the relation $EK_f = f\ (CK_f)$ at CK_r (Schneider, 1997a). Putting the value of CK_r in the place of *x*, corresponding value of EK_f was obtained, which is essentially EK_r. The calculated EK_r for BAU and Barisal soil was 0.049 and 0.109 cmol kg^{-1}, respectively (Table 5). The value of EK_r has great importance because it is the critical value of exchangeable K at which ΔNEK = 0, below which release of nonexchangeable K was initiated. EK_r value of 0.17, 0.23 and 0.21 cmol kg^{-1} was reported in surface layer of Crowely silt loam, Dundee silt loam and Norwood silt loam soil of the USA (Wang et al, 2004). The EK_r value of the corresponding soils was lower in the subsurface layers. Jalail and Kolachi (2007) reported EK_r in the range of 1.75 – 15.4 mmol kg^{-1} in calcareous soils of Iran.

Minimum exchangeable K^+ (E_{min}) was also derived from Fig. 7. When CK_f approaches zero, EK_fremains > 0, thus, EK_f tends towards a nonzero value, which would be defined as E_{min}.The E_{min} was 0.049cmol kg^{-1} in BAU soil and 0.114 cmol kg^{-1}in Barisal soil (Table 5).In BAU soilE_{min} represent 70% of the exchangeable K, while in Barisal soil it was 57% of the exchangeable K. Higher proportion of E_{min} to exchangeable K in BAU soil compared to Barisal soil suggest that lower K supplying ability of the former than the latter. Potassium ions corresponding to E_{min} are retained by the soil and do not exchange with Ca^{2+}, despite their extraction by NH_4OAc (Schneider, 1997a, b) and may represent the amount of K^+ fixed on some clay interlayer sites and is a fraction of EK which is almost unavailable to plants. If EK could reach this point value then the K^+ concentration in solution would reach zero (Schneider, 1997a, b).

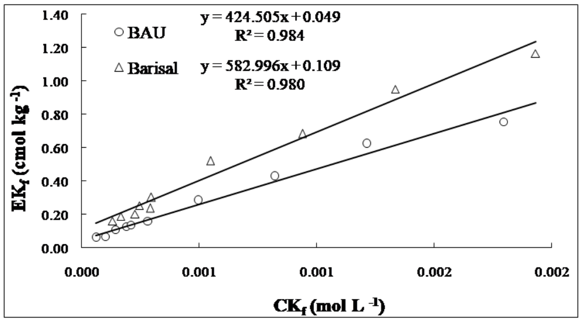

Figure 7.Relationship between final exchangeable K+ and K+concentration in soil solution in BAU and Barisal soils.

It should be correlated with the soil E_{min} that is reached after extensive cropping (Tabatabaiand Hanway, 1969). In soils where EK is far from E_{min}, EK contributes a larger proportion of K^+ supply. JalaliandKolahchi (2007) reported the E_{min} varied from 0.68 to 9.00 mmol kg^{-1} (17.8%–89.6% of the EK) in 14 soils of Iran.

Conversion of added potassium to nonexchangeable pool

Conversion of added K to nonexchangeable pool was derived from the linear relationship between ΔNEK and initial constrain (Φ).The slope of the linear regression line is considered as the proportion of the added K to the nonexchangeable pool, which is represented by β. Fig.8 shows the relationship between ΔNEK and Φ. The slope for Barisal soil was 0.089 and that for BAU soil was 0.109, which indicates that 8.9% of the added K in Barisal soil and 10.9% in BAU soil would be converted to nonexchangeable pool.

The slope (ß) between the change in NEK and the initial constrain indicates the impact of the nonexchangeable pools on K^+ dynamics in the soil solution system (Schneider, 1997b; Wang et al., 2004).The large the ß the greater the portion of added K^+ converted to NEK (fixed) at positiveΦ or the more fixed K^+ released at negativeΦ (Wang et al., 2004). Soil ability for release K^+ or fixation for all soils ranged from 0.041 to 0.183, with a mean of 0.080, indicating that 4%-18% of added K^+were converted to NEK (Jalali and Kolahchi, 2007).

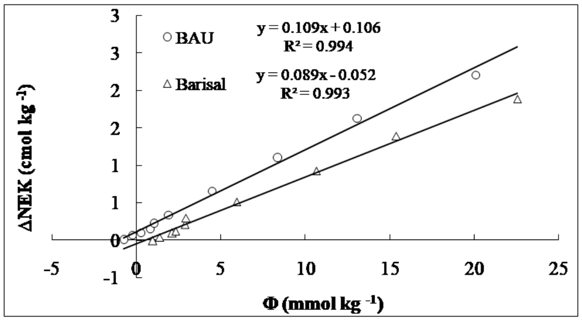

Figure.8 Change in nonexchangeable K^+ as a function of initial constrain for BAU and Barisal soils.

When CK_i equals CK_0, there is no exchange, release or fixation of K^+. This is consistence with the existence of equilibrium between solution K^+, EK and fixed K^+ (Mortland, 1961; Schneider, 1997c). The soils containing little K^+ release less K^+ or fix more K^+ than enriched soils. There was a negative correlation between α and β (Wang et al., 2004). Thus, it can be expected that when K^+ fertilizer is applied to a soil having a large α and a small β, much of the K^+ is held on exchangeable sites and would be available to plants without being fixed (Wang et al., 2004). There was a linear relation between PBC and β, indicating the PBC does not only depend on exchange properties but also on soil release and fixation properties (Schneider, 1997b). When CK_i equals CK_0; there was no exchange, release or fixation.

CONCLUSIONS

The Old Brahmaputra floodplain (BAU) and Ganges tidal floodplain (Barisal) soils differed widely in solution, exchangeable, nonexchangeable and total K. All the forms of K were higher in Barisal soil than BAU soil. Barisal soil released 2.7 times higher solution K and 2.45 times higher exchangeable K than BAU soil. Waterlogging increased K availability in both soils, however, but the interaction of soil × moisture level on K availability was not significant. Recovery of applied K by NH_4OAc extraction was higher in Barisal soil than BAU soil. Barisal soil had higher CR_0, CK_0, EK_0, E_{min}, CK_r, EK_r, PBC_{exch} and α than BAU soil. On the other hand, BAU soil showed higher $PBC_{Non-exch}$and PBC_{Total}, and β than Barisal soil. The lower value of E_{min} (0.049cmol kg $^{-1}$) with lower value of exchangeable K 0.07 cmol kg^{-1} indicate that the soil's E_{min} is 70% its exchangeable K level. It means the BAU soil's has been highly exhausted may be due to intensive cropping without proper management of K fertilizer. E_{min} in Barisal soil was 57% of the exchangeable K, which experienced less K mining than BAU soil. Conversion of applied K into exchangeable and nonexchangeable pool in Barisal soil was 35 and 8.9%, respectively, compared to 25 and 10.9%, respectively, in BAU soil. The results suggest that a combined assessment of CR_0, CK_0, EK_0, E_{min}, CK_r, EK_r, and exchangeable and nonexchangeable buffering capacity of soil would be useful for predicting long-term K management in soils.

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