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Changes in mineral composition and bioavailable potassium under long-term fertilizer use in cotton-wheat system

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Abstract

Changes in soil bioavailable potassium (K) and mineral composition determines long-term sustainability of a cropping system. After 5-year fertilizer treatments to cotton-wheat rotation, changes in soil mineralogy and the K-availability indices were investigated to help devise optimum fertilization plan. The soil contained mica, quartz, and feldspars in the sand and silt fractions; mica and kaolinite with small amount of quartz, smectite and vermiculite in the coarse clay; and mainly smectite and some vermiculite and mica in the fine clay fraction as determined by X-ray diffraction and total K and Ca/Mg and K/NH_4 CEC properties. The sand and silt from AB (14-27 cm) horizon of NPK treatment had stronger mica peak than that of NP. Treatment effect on mica in Ap (0-14 cm) and Bwk (27-43 cm) horizons was limited probably due to sedimentation of fresh minerals entering the field with canal irrigation and less root activity in Bwk horizon. Boiling HNO_3-extractable K varied from 196 to 432 mg 100 g^{-1} sand and from 181 to 197 mg 100 g^{-1} silt from the fallow profile. The NPK treatment contained greater boiling HNO_3-extractable K in the sand and silt fractions as well as the soil NH_4OAc-extractable K than the NP. The soil NH_4OAc-extractable K ranged from 75 to 124 mg kg^{-1} soil and K-fixation ranged from 27.0 to 42.5 mg 100 g^{-1} soil. There was no long-term fertilizer treatment effect on soil K-fixation. The study conclude only marginal changes in soil bio-available K and in the mineral composition due to K-less fertilization in the canal irrigated cotton-wheat system in Southern Pakistan (Sindh).

Key words: Soil mineral composition, bio-available potassium, long-term fertilizer treatments, cotton-wheat system

Introduction

Potassium (K^+) is an essential plant nutrient taken up from soil in large quantity. Soil solution- and exchangeable-K are in equilibrium and, collectively, known as the readily available K pool (bio-available). The bioavailable K pool is only a minor fraction of the total soil K reserve (Huang, 2005). On the other end of bio-available pool, non-exchangeable-K occurs in soil micas (biotite and muscovite) and in K-feldspar structure. The K containing mineral vary with the source of parent material and the degree of weathering (Portela, 1993; Sharma *et al*., 2006; Simonsson *et al*., 2007). Thus, K chemistry processes, which are important issues in long-term sustainability of a cropping system, should be understood locally. Internationally, changes in mineralogical composition and bio-available K indices under intensive crop production without K fertilization have been investigated due to risks to long-term productivity (Singh and Goulding, 1997; Srivastava *et al*., 2002; Holmqvist *et al*., 2003; Bedrossian and Singh, 2004). Long-term studies on changes in mineralogical composition and soil K in the alluvial plain have been carried out under rice-wheat (Akhtar and Ali, 1995) and sugarcane-based crop rotations (Waheed, 1998) but no parallel information exists for the cotton-wheat cropping system.

Soils rich in K fix lower amounts of added K as compared to soils low in K (Dhaliwal *et al*., 2006) and the fertilizer applications are less effective (Blake *et al*., 1999). Release of K from the non-exchangeable pool into bioavailable pool depends upon equilibrium solution K concentration (Basset, 1959; Simrad *et al*., 1992), particle size distribution and mineral characteristics (Norrish, 1973), biological activity (April and Keller, 1990), plant species (Robert and Berthelin, 1986; Wang *et al*., 2000; Moritsuka *et al*., 2004) and soil pH (Choudhury and Khanif, 2003) and solution composition (Fanning *et al*., 1989). An exhaustive uptake of K under intensive crop cultivation may deplete the equilibrium solution K below the critical limit for release of non-exchangeable K and enhance weathering rate of soil mica (Hinsinger and Jailard, 1993; Hinsinger *et al*., 1993). Since the critical K concentration of equilibrium solution - below which the interlayer K is released - is greater for trioctahedral mica (biotite) compared to a dioctahedral (muscovite) (Rausell-Colom *et al*., 1965; Norrish, 1973), biotite weathers first (and faster) than muscovite (Scott and Smith, 1966). Muscovite weathers only under very low solution K concentration which is lower than the critical limit for optimum production of most arable crops; and upon weathering its structure almost decomposes. Biotite weathers

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to vermiculite (Mortland *et al*., 1956; Mortland, 1958) upon release of interlayer-K. Partially weathered mica and vermiculite retain K irreversibly (McDowell and Marshall, 1962; Newman, 1970; Sawhney, 1972) and compete with plant roots for applied K.

Transformations of phyllosilicates and changes in soil K fractions caused by long-term cropping differ contrastingly due to differences in the parent material the soils are derived from and the agro-climatic conditions that affect the K^+ uptake from soil solution. Singh and Goulding (1997) reported no change in mica and no depletion in K due to 153-year winter wheat cropping at Rothamsted Experimental Station. Contrarily, depletion in non-exchangeable K in 27-year NP fertilization compared to NPK+FYM was reported in an alluvial mixed mineralogy, Typic Ustochrept under maize-wheat-cowpea cropping system (Srivastava *et al*., 2002). Since abundance of soil moisture and fibrous rooting system enhance weathering, transformation of mica to vermiculite and depletion in extractable and non-exchangeable K was reported in a clay loam, mixed mineralogy hyperthermic Ustic Haplocambid under 7-years rice-wheat cropping (Akhtar and Ali, 1995). Similar changes have been reported for sugarcane production in the same soil (Waheed, 1998).

Soils in the alluvial plain (Pakistan) are intensively cultivated generally without application of fertilizer K which is causing a negative K-balance (Ahmad, 2000). The soils contain both biotite and muscovite and K-feldspars in the sand, silt, and coarse clay fractions inherited from the parent material (Ahmed *et al*., 1986). Continuous crop production without K application may result in mica weathering particularly that of biotite into vermiculite (and smectite) and decomposition of feldspar structure over a longer period of time. The present study reports comparative changes in mineralogical composition of various size fractions, soil K fractions, and K fixation characteristics caused by 5-year NP and NPK fertilizer treatments in the irrigated cotton-wheat cropping system in southern Pakistan (Sindh) to help devise sustainable fertilization plan.

Materials and Methods

Site description

The site occurs in a semi-arid subtropical climate (annual rainfall 175 mm per annum) located 25°25'25"N and 68°32'06"E. The site is a shallow phase of Sultanpur soil series classified as Ustic Haplocambid. It is deep, well drained, coarse textured, moderately calcareous soil developed in the Subrecent mixed mineralogy alluvium derived from the Himalayan range. The fertilizer treatments had been applied for the past five years (1991 to 1996) at the time of sampling. The selected fertilizer treatments were: (i) Control, no chemical fertilizer applied to both cotton (*Gossypium hirsutum*) and wheat (*Triticum aestivum*); (ii) NP, 120-60 kg ha^{-1} to cotton and 120-90 kg ha^{-1} to wheat; and (iii) NPK, 120-60-30 kg ha^{-1} to cotton and 120-90-60 kg ha^{-1} to wheat. Field plots with three replications were sampled from three upper genetic horizons, i.e. Ap (0-14 cm), AB (14-27 cm) and Bwk (27-43 cm). Separately, samples were taken from the adjoining soil profile (which remained fallow throughout the experimental period) for comparison. The soil samples were air-dried and crushed to pass through a 2mm sieve.

Particle size fractionation and mineralogical analysis

Particle size fractionation of the soil into sand (+50 μm), silt (50-20 μm), coarse clay (2-0.2 μm) and fine clay (< 0.2 μm) was carried out after chemical treatments to remove soil $CaCO_3$, organic matter, and iron oxides (Jackson, 1979). $CaCO_3$ was removed by treatment with 1N NaOAc buffered to pH 5 at 75 °C for 30 min; soil organic matter was removed by 30 mg 100 g^{-1} H_2O_2 at 70 to 80 °C. The iron oxides were removed with citrate-bicarbonate dithionite (Na-citrate to $NaHCO_3$ ratio 1:8) buffered at pH 7.3. The soil suspension was dispersed in 0.02 M Na_2CO_3 solution (pH 9.5) by a 30 s sonification. The sand was separated by wet sieving through a 0.51 μm nominal pore size screen and silt by low speed centrifuging. From the remaining clay suspension, the coarse clay (2-0.2 μm) and fine clay (< 0.2 μm) were separated by repeated high speed centrifugation. Both the clay fractions were dialyzed to remove salt and freeze-dried. The sand and silt fractions were dried in oven. The sand was powdered finely in the presence of acetone in pestle and mortar. Randomly oriented mounts of the sand and silt were x-rayed at a scanning speed of $1° \, 2\theta \, min^{-1}$ by using a Cu K α radiation.

Vermiculite and smectite in the clay fractions were determined from Ca/Mg and K/NH_4 exchange capacity (Jackson, 1979). The clay was saturated with Ca by repeated washing with IN $CaCl_2$ solution and the exchangeable Ca was displaced by Mg by repeated washing with IN $MgCl_2$ solution. Similarly, K/NH_4 was determined by saturating the same clay with K by repeated washing with IN KCl solution. After K-saturation the clay was heated at 105 °C and exchangeable K was displaced by 1N NH_4Cl (Jackson, 1979). The displaced Ca and K were assayed by atomic absorption spectrophotometer. Vermiculite was calculated assuming CEC 140 mol_c kg^{-1} vermiculite and smectite assuming 105 molc kg^{-1} smectite. Five mol_c CEC kg^{-1} sample was ascribed to the edge surfaces and subtracted in each case.

Soil potassium fractionation

Ammonium acetate extractable K was extracted with 1N NH_4OAc solution buffered to pH 7 (Helmke and Sparks, 1996). Nitric acid extractable K was determined for the sand and silt fractions by boiling 1 g sample in 25 mL 1N HNO_3 for 10 min and making the final volume to 100 mL with deionized water (Helmke and Sparks, 1996). Total K in the sand, silt, coarse clay, and fine clay fractions was determined after digestion of the samples in HF + Aqua regia and K was measured by a flame photometer. Mica was calculated assuming 10 mg $100g^{-1}$ K_2O in mica crystal (Jackson, 1979).

Potassium fixation capacity

Potassium fixation capacity of soil was determined by equilibrating 3g K kg^{-1} and K was extracted with 1N NH_4OAc (pH 7) after 4 alternate wetting and drying cycles. The figure 3g K kg^{-1} soil was found to be the maximum fixation potential after a trial study. Potassium added but not recovered was assumed to be fixed (Sharply, 1990).

Results and Discussions

Characteristics of the soil profile

Particle size distribution suggested that the Ap (0-14 cm) was silty clay loam and the subsurface horizons were silt loam as calculated on $CaCO_3$-free basis (data not presented). The sand/silt ratio suggested lithological breaks at a depth of 43 cm and another at 92 cm depth. There was no evidence of translocation of clay in the profile as determined from the coarse clay to fine clay ratio (data not presented). The sand and silt fractions from the profile were composed of mica, quartz and feldspars as determined from random powder diffraction of the size fractions (data not presented). Mica was recognized by X-ray diffraction lines at 10.0, 5.0 and 3.33 Å. Quartz was recognized by 4.26 Å line as the second order peak of quartz occurs at same position (3.34 Å) as that of mica at 3.33 Å (Fanning *et al.*, 1989). Feldspar was recognized by the occurrence of multiple peaks between 3.29 Å to 3.15 Å (Brown, 1980; Huang, 1989). The occurrence of diffraction peaks at 4.21 Å and 3.29 Å was considered indicative of K-feldspar. As determined by total K analysis, mica in the sand varied from 20 to 28 mg 100 g^{-1} and in the silt size from 15 to 26 mg 100 g^{-1}. The mixed mineralogy in the sand and silt size fractions was previously reported for the alluvial other soils (Ahmed *et al.*, 1977; Razzaq and Herbillon, 1979; Akhtar and Dixon, 1993; Akhtar and Dixon, 2007), and for other soils in the area (Qureshi *et al.*, 1996). Mica increased with profile depth in the upper three horizons, which were lithologically uniform. This depth trend suggested limited mica weathering in the Ap horizon. However, as determined by the total K analysis, there was no consistent depth trend noted for sand and silt size mica in the profile mainly because both feldspar and mica, which had opposite depth trend, contributed to the total K analysis.

The coarse clay was composed of mainly mica and kaolinite with small amount of smectite, vermiculite and quartz as determined by X-ray diffraction, total chemical analysis and Ca/Mg and K/NH_4 CEC properties. Mica in coarse clay fraction varied from 20 to 52 mg 100 g^{-1} in the profile as determined by the total K analysis. In all the three lithological units, the coarse clay mica generally increased with depth which may be due to weathering in the surface horizons of the profile in various episodes. There was no consistent trend of smectite in the coarse clay fraction with the profile depth. Lack of depth trend throughout the profile suggested that the smectite was inherited from parent material. The fine clay was composed of smectite, vermiculite and mica. Mica in the fine clay fraction ranged from 16 to 20 mg 100 g^{-1}, vermiculite 30 to 50 mg 100 g^{-1} and smectite ranged from 40 to 47 mg 100 g^{-1}. There was more fine clay mica in the subsurface horizons of the upper two lithological units than the surface horizons. Also, there was the least mica at the surface horizon of the each lithological unit. The fine clay smectite distribution had no depth trend; therefore, fine clay minerals also appeared to be inherited from the parent material (Qureshi *et al.*, 1996; Razzaq and Herbillon, 1979). Thus, the profile was at an early stage of development and the upper three horizons were lithologically uniform and provide basis for evaluating the treatment effect.

Treatment effect on mineralogical composition

Sand and silt mineral composition

Compared to NP, the NPK treatment had more intense X-ray diffraction peaks representative of mica and K-feldspar in the sand fraction from the AB (14-27 cm) horizon (Figure 1). Sand and silt size mica and K-feldspar are important as source of non-exchangeable K in the soils. The study suggested greater weathering of the sand silt size mica in the K-less treatments applied to Cotton-Wheat cropping as previously reported for the Rice-Wheat system (Akhtar and Ali, 1995). In all the NP replicates reduction in the first order mica peak (10.0 Å) was noted but not in the second order peak at 5.0 Å. This observation suggested weathering of only trioctahedral mica (biotite) which is in line with previous studies under controlled conditions (Scott and Smith, 1966; Mortland *et al.*, 1956; Mortland, 1958; Huang, 2005). Most NPK treatment plots had strong K-feldspar peak. Treatment effect on mica and K-feldspar in Ap (0-14 cm) and Bwk (27-43 cm) horizons was not consistent. Probably, sedimentation of fresh minerals with irrigation water and limited root activity in Bwk horizon reduced the treatment effect (Figure 1). As determined by total K analysis sand size mica varied from 20 to 28 mg 100 g^{-1}. There was no consistent depth trend noted mainly because both feldspar and mica, which had opposite depth

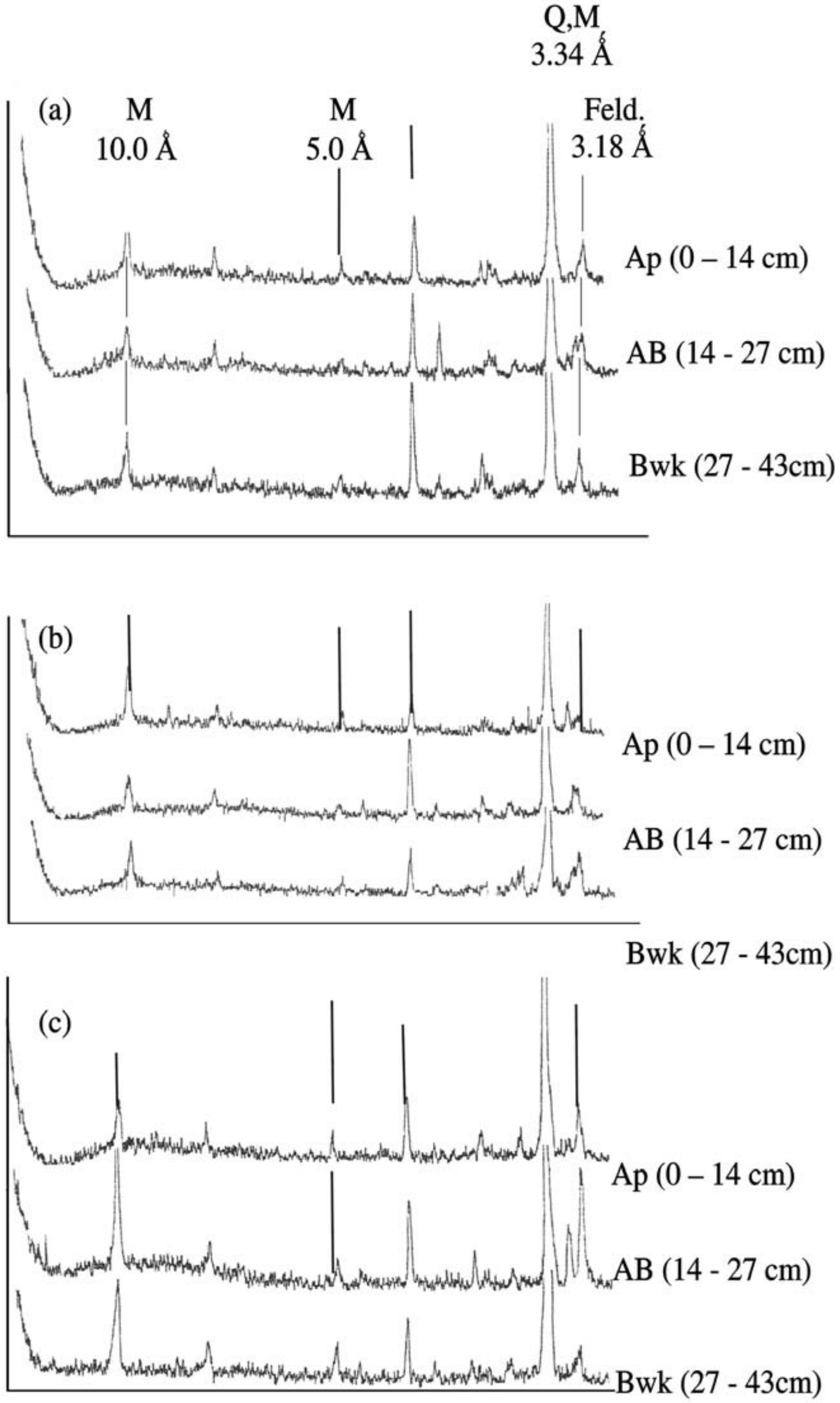

Figure 1. X-ray diffraction pattern of random powder mounts the sand fraction from the 5-year fertilizer treatment plots in irrigated cotton-wheat cropping system: (a) Control, (b) NP and (c) NPK, M stands for mica; Q, quarts; and Fld, feldspar.

trend, contributed to the total K analysis. Mica in the silt fraction ranged from 18 to 20 mg 100 g^{-1} (Table 1) and the Control had slightly greater mean values (21.4 mg 100 g^{-1}) as compared to the NP and NPK treatments (18 mg 100 g^{-1}).

Soil clay mineral composition

The NPK had greater coarse clay mica in the Ap (0-14 cm) horizon (41 mg 100 g^{-1}) than the NP (34 mg 100 g^{-1}) and Control (29 mg 100 g^{-1}) treatments as determined by total K analysis (Table 1). The fine clay mica ranged from 15.4 to 35.7 mg 100 g^{-1} and averaged to 24 mg 100 g^{-1}. The NPK treatment had greater mica in both the clay fractions in the Ap (0-14 cm) horizon than the Control and NP treatments. This may suggest greater weathering in the NP than NPK in the surface horizon. There was limited treatment effect in AB (14-27 cm) and Bwk (27-43 cm) horizons. Mica, vermiculite and smectite in the soil clays are important as source (mica) and sink (partially weathered mica and vermiculite) of K. Quantification of vermiculite and smectite was based on the CEC properties of the clays. Vermiculite in the coarse clay ranged from 4 to 8.5 mg 100 g^{-1} while in fine clay vermiculite ranged from 43 to 58 mg 100 g^{-1} (Table 2). Generally, in both the clay fractions, vermiculite increased towards the surface horizon, which was a combined effect of treatment and soil genesis (Table 2). Smectite in the coarse clay ranged from 19 to 22 mg 100 g^{-1} while in fine clay it ranged from 41 to 50 mg 100 g^{-1} which did not vary due to the treatments in both the clay fractions (Table 3). In the Ap (0-14 cm) horizon, the coarse clay fraction had greater smectite in NP than NPK treatment. The Control had greater smectite mean values followed by NP treatment in the fine clay fraction than the NPK. Treatment effect on smectite content was obvious only in the Ap (0-14 cm) horizon in the coarse clay fraction (Akhtar and Ali, 1995).

Table 1. Treatment effect on mica content in the silt, coarse clay and fine clay fractions

Horizon	Depth	Profile[$]	Control	NP	NPK
	cm		----------------------- mg 100 g^{-1} ------------------------		
			Silt (50-2 μm)		
Ap	0-14	19.0	21.4 (1.2)	17.7 (1.9)	18.3 (1.2)
AB	14-27	19.1	19.9 (3.6)	18.7 (2.2)	17.6 (1.1)
Bwk	27-43	22.2	18.1 (2.5)	17.5 (0.1)	19.6 (1.2)
			Coarse clay (2-0.2 μm)		
Ap	0-14	28.8	29.3 (13.4)	33.6 (18.3)	41.3 (18.7)
AB	14-27	38.9	38.9 (15.0)	47.5 (14.2)	38.4 (13.7)
Bwk	27-43	36.0	29.8 (7.1)	32.2 (13.4)	31.7 (18.7)
			Fine clay (< 0.2 μm)		
Ap	0-14	15.8	36.7 (5.1)	19.7 (6.8)	22.6 (4.6)
AB	14-27	20.2	34.1 (14.0)	22.1 (10.8)	31.7 (18.0)
Bwk	27-43	15.8	19.2 (3.6)	20.6 (3.6)	15.8 (0.0)

[$] The profile remained fallow through out experimental period

The number in parentheses is one standard deviation on the respective mean.

Table 2. Treatment effect on vermiculite content in the clay fractions

Horizon	Depth	Profile[$]	Control	NP	NPK
	cm		----------------------- mg 100 g^{-1} ------------------------		
			Coarse clay (2-0.2 μm)		
Ap	0-14	1.7	5.9 (1.9)	3.7 (4.0)	8.5 (1.1)
AB	14-27	3.5	3.7 (1.0)	4.0 (2.3)	4.9 (3.4)
Bwk	27-43	3.7	4.7 (1.1)	2.7 (3.2)	8.5 (6.0)
			Fine clay (< 0.2 μm)		
Ap	0-14	41.4	47.0 (13.0)	46.7 (5.4)	52.1 (12.0)
AB	14-27	46.9	45.3 (9.7)	43.7 (12.0)	53.5 (20.9)
Bwk	27-43	46.2	43.1 (10.9)	46.2 (13.8)	35.3 (10.9)

[$] The profile remained fallow through out experimental period

The number in parentheses is one standard deviation on the respective mean.

Treatment effect on potassium fractions

Boiling HNO_3-extractable potassium

Potassium extracted by boiling 1N HNO_3 was 196, 432, and 378 mg 100 g^{-1} sand and 181, 198, 197 mg 100 g^{-1} silt from Ap (0-14 cm), AB (14-27 cm) and Bwk (27-43 cm) horizons of the fallow soil profile, respectively (Table 4). At the surface horizon the NP treatment had lesser K extracted by boiling HNO_3 from the sand and silt fraction (Table 4) and varied significantly with the treatments ($p \geq 0.088$). Similar decrease in release of boiling HNO_3-extractable K has been reported previously for the sand and silt fractions taken from long-term K-less fertilizer treatments (Akhtar and Ali, 1995). In both the sand and silt fractions, Ap horizon had the least K released, which corresponded to lesser mica content rather than feldspar (Figure 1). Therefore, K release appeared to be controlled by mica content than the feldspar in both the fractions. Mica is considered better source of K than the feldspar (Huang, 1989).

Table 3. Treatment effect on smectite content in the clay fractions

Horizon	Depth	Profile$^{\$}$	Control	NP	NPK
	cm			Coarse clay (2-0.2 μm)	
			------------------------	mg 100 g^{-1}	------------------------
Ap	0-14	18.2	21.4 (0.8)	22.5 (3.0)	20.0 (2.2)
AB	14-27	19.0	20.9 (0.6)	19.0 (2.6)	19.5 (1.2)
Bwk	27-43	19.8	18.9 (4.8)	22.1 (2.1)	21.3 (1.0)
				Fine clay (< 0.2 μm)	
Ap	0-14	43.4	40.9 (4.2)	41.7 (3.2)	42.2 (2.4)
AB	14-27	39.5	43.2 (2.6)	41.7 (3.1)	42.1 (5.3)
Bwk	27-43	42.5	49.6 (6.2)	48.3 (6.7)	47.5 (9.9)

$^{\$}$The profile remained fallow through out experimental period
The number in parentheses is one standard deviation on the respective mean.

Table 4. Treatment effect on K-availability indices

				Fertilizer treatment	
Horizon	Depth	Profile$^{\$}$	Control	NP	NPK
	cm		------------------------	mg 100 g^{-1}	------------------------
				Boiling HNO_3-extractable K in sand	
Ap	0-14	196	81 (70)	150 (25)	176 (69)
AB	14-27	432	163 (34)	234 (76)	165 (61)
Bwk	27-43	378	154 (46)	158 (171)	295 (91)
				Boiling HNO_3-extractable K in silt	
Ap	0-14	181	195 (17)	167 (27)	219 (30)
AB	14-27	198	224 (42)	197 (40)	225 (22)
Bwk	27-43	197	213 (49)	175 (10)	243 (33)
				NH_4OAc-extractable K in soil	
Ap	0-14	124	155 (21)	133 (36)	147 (21)
AB	14-27	97	162 (38)	134 (45)	161 (35)
Bwk	27-43	75	88 (76)	85 (24)	117 (46)
				K-fixation by soil	
Ap	0-14	37.5	53.9 (60.9)	28.4 (25.1)	27.5 (25.5)
AB	14-27	27.0	27.5 (23.9)	30.5 (14.3)	26.1 (10.6)
Bwk	27-43	42.5	34.8 (15.8)	35.7 (5.4)	40.0 (20.3)

$^{\$}$The profile remained fallow through out experimental period
The number in parentheses is one standard deviation on the respective mean.

Ammonium acetate extractable potassium

The ammonium acetate extractable K ranged from 75 to 124 mg kg^{-1} soil and decreased with depth in the upper 43 cm of the fallow soil profile. The Ap (0-14 cm) and AB (14-27 cm) horizons had significantly greater NH_4OAc-extractable K ($p \geq 0.0002$) than Bwk (27-43 cm). The fertilization without fertilizer K (NP treatment) NH_4OAc-extractable K in soil decreased compared to NPK and Control at all depths up to 43 cm (Table 4). Yet, it remained adequate for crop production NP treatment plots. Soil test K level of 80 to 105 mg kg^{-1} soil is considered medium and 140 to 150 mg kg^{-1} soil is desired for optimum crop production. With continuous application of N and P fertilizers a marginal change in available K was reported in rice-wheat system (Kumar and Yadav, 2001; Akhtar and Ali, 1995). Since amount of clay controls cation exchange, NH_4OAc-extractable K was positively correlated with both the clay fractions (Helmke and Sparks, 1996).

Potassium fixation capacity

The K-fixation values ranged from 27.0 to 133.4 mg 100 g^{-1} soil in the profile (Table 4). In general, fixation increased with profile depth, being the lowest in the upper lithological unit (0-43 cm) (Table 4). Treatment effect on K-fixation could not be ascertained. The Control had greater K-fixation than NP and NPK treatments in the Ap horizon (Table 4). There was a positively significant correlation between the K-fixation and both the fine and coarse clay fractions ($p \geq 0.0001$; 0.0001, respectively).

The soil under study was at early stage of profile development and contained an appreciable amount of mica and feldspars in the sand and silt size fractions in all lithological units. The clay fraction also had mica beside more ubiquitous mineral such as kaolinite, quartz, smectite and vermiculite. The effect of long-term fertilizer application was evident only in the AB horizon where K-less treatments enhanced the weathering of sand and silt size mica and consequently, boiling HNO_3-extractable K in these fractions decreased. The K-less fertilization decreased soil NH_4OAc-extractable K compared to NPK and Control but, it remained adequate for crop production even in the NP treatment plots. There was limited treatment effect on K-fixation by soil. The irrigation applied from canal contained 7.2 mg K L^{-1} and that of from tubewell was 6.48 mg K L^{-1} (Shakir *et al*., 1994). The canal water also brings in fresh mineral matter and which has contributed K (Shakir *et al*., 1994). On consumptive water use basis, the average K addition was 26 kg K ha^{-1} to wheat and 38 kg K ha^{-1} to cotton from canal irrigation. Similarly, 23 kg K ha^{-1} to wheat and 34 kg K ha^{-1} to cotton from tubewell irrigation (Shakir *et al*., 1994). In the study, K uptake by the wheat crop of 1994-95 was 29.5 kg ha^{-1} in Control, 106.4 kg ha^{-1} in NP, and 107.1 kg ha^{-1} in NPK treatment plots ($LSD_{0.05}$ of 6.9 kg ha^{-1}). Interestingly, the K removal was not different with and without fertilizer K application. With annual uptake of 250 kg K ha^{-1} by the cotton (Jones, 2003), it appeared that crop K requirement was effectively met from the non-exchangeable K sources in the NP treatment.

References

Ahmad, N. 2000. Integrated plant nutrition management in Pakistan: Status and opportunities. In: Proceeding of Symposium on Integrated Plant Nutrition Management. N. Ahmed and A. Hamid (eds.). National Fertilizer Development Centre, Islamabad.

Ahmed, M., J. Ryan and R.C. Paeth. 1977. Soil development as a function of time in the Punjab river plains of Pakistan. *Soil Science Society of America Journal* 41: 1162-1166.

Ahmed, M., M. Akram, M.S. Baig, M.Y. Javad and Raiz-ul-Amin. 1986. Proceeding XII International Forum on Soil Taxonomy and Agro-technology Transfer. Lahore October 1985. 2nd vol. Field Excursions. Soil Survey of Pakistan, Multan Road Lahore and Soil Management Services USA.

Akhtar, M.S. and A. Ali. 1995. Micaceous mineral transformations and potassium availability under rice-wheat rotation. p. 515-519. In: Clays: Controlling the environment. G.J. Churchman, R.W. Fitzpatrick and R.A. Eggleton (eds.) Proceeding of the 10th International Clay Conference, Adelaide. Australia 1993. CSIRO Pub. Melbourne, Australia.

Akhtar, M.S. and J.B. Dixon. 1993. Mineralogy and clay layer charge properties of surface soils of Pakistan. *Clay Research* 12: 22-23.

Akhtar, M.S. and J.B. Dixon. 2007. Mineralogical characteristics and potassium quantity/intensity relation in three Indus Basin soils. *Pedosphere* (submitted).

April, R. and D. Keller. 1990 Mineralogy of the rhizosphere in forest soils of the eastern United States. Mineralogical studies of the rhizosphere. *Biogeochemistry* 9: 1-18.

Bassett, W.A. 1959. The origin of vermiculite deposit at Libbly, Montana. *American Mineralogist* 44: 282-299.

Bedrossian, S. and B. Singh. 2004. Potassium adsorption characteristics and potassium forms in some New South Wales soils in relation to early senescence in cotton. *Australian Journal of Soil Research* 42: 747-753.

Blake, L., S. Mercik, M. Koerschens, K.W.T. Goulding, S. Stempen, A. Weigel, P.R. Poulton and D.S. Powlson. 1999. Potassium content in soil, uptake in plants and the potassium balance in three European long-term field experiments. *Plant Soil* 216: p.361-410.

Brown, G. 1980. Associated minerals. In: Crystal structures of clay minerals and their X-ray identification. G.W. Bindley and G. Brown (eds.) p.361-410. Mineral Society, London.

Choudhury, A.T.M.A. and Y.M. Khanif. 2003. Potassium adsorption behavior of three Malaysian rice soils. *Pakistan Journal of Science and Industrial Research* 46: 117-121.

Dhaliwal, A.K., R.K. Gupta, Yadvinder-Singh and Bijay-Singh. 2006. Potassium fixation and release characteristics of some benchmark soil series under rice-wheat cropping system in the Indo-Gangetic Plains of Northwestern India. *Communications of Soil Science and Plant Analysis* 37: 827-845.

Fanning, D.C., V.Z. Keramidas and M.A. El-Desoky. 1989. Micas. p. 551-634. In: Minerals in soil environment. J.B. Dixon and S.B. Weed (eds.) Soil Science Society of America, WI. USA.

Helmke, P.A. and D.L. Sparks. 1996. Lithium, sodium and potassium. p. 551-574. In: Methods of Soil Analysis, part 2, Chemical and Microbiological Properties. D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Sultanpour, M.A. Tabatabai, C.T. Jhonston, and M.E. Sumner (eds.). Soil Science Society of America, WI. USA.

Hinsinger, P. and B. Jaillard. 1993. Root-induced release of interlayer potassium and vermiculitization of phologopite as related to potassium depletion in the rhizosphere of ryegrass. *Journal of Soil Science* 44: 525-534.

Hinsinger, P., F. Elsass, B. Jaillard and M. Robert. 1993. Root-induced irreversible transformation of trioctahedral mica in the rhizosphere of rape. *Journal of Soil Science* 44: 535-545.

Holmqvist, J.A.F. Ogaard, I. Öborn, A.C. Edward, Mattsson and H. Sverdrup. 2003. Application of the PROFILE model to estimate potassium release from mineral weathering in Northern European agricultural soils. *European Journal of Agronomy* 20: 149-163.

Huang, P.M. 1989. Feldspars, olivines, pyroxenes and amphiboles. p. 227-292. In: Minerals in soil environment. J.B. Dixon and S.B. Weed (eds.). Soil Science Society of America, WI. USA.

Huang, P.M. 2005. Chemistry of potassium in soils. p. 975-1050. In: Chemical processes in soils. M.A. Tabatabai and D.L. Sparks (eds.) Soil Science Society of America, WI. USA.

Jackson, M.L. 1979. Soil chemical analysis: Advanced course. 2nd edition, Department of Soil Science, University of Wisconsin, Madison. USA.

Jones, J.B. 2003. Agronomic Handbook: Management of crops, soils and their fertility. CRC Press. Boca Raton, Florida. USA.

Kumar, A. and D.S. Yadav. 2001. Long-Term effects of fertilizers on the soil fertility and productivity of a Rice-Wheat system. *Journal of Agronomy and Crop Science* 186: 47-56.

McDowell, L.L. and C.E. Marshall. 1962. Ionic properties of mica surfaces. *Soil Science Society of America Proceeding* 26: 547-551.

Moritsuka, N., J. Yanai and T. Kosaki. 2004. Possible processes releasing non-exchangeable potassium from the rhizosphere of maize. *Plant Soil* 258: 261-268.

Mortland, M.M., K. Lawton and G. Uehara. 1956. Alteration of biotite to vermiculite by plant growth. *Soil Science* 82: 477-481.

Mortland, M.M. 1958. Kinetics of potassium release from biotite. *Soil Science Society of America Proceeding* 22: 503-508.

Newman, A.C.D. 1970. Cation exchange properties of mica II Hysteresis and irreversibility during potassium exchange. *Clay Minerals* 8: 267-272.

Norrish, K. 1973. Factors in the weathering of mica to vermiculite. In: Proceeding of 4th International Clay Conference 1972. J.M. Serratosa (ed.). Madrid Div de Ciencias C.S.I.C., Madrid. p. 417-432.

Portela, E.A.C. 1993. Potassium supplying capacity of northeastern Portuguese soils. *Plant Soil* 154:13-20.

Qureshi, S., M.S. Akhtar and K.S. Memon. 1996. Mineralogical composition of two Sindh alluvial soils in relation to K availability. *Pakistan Journal of Soil Science* 11: 27-38.

Rausell-Colom, J.A., T.R. Sweatman, C.B. Wells and K. Norrish. 1965. Studies in the artificial weathering of mica. p. 40-72. In: Experimental Pedology. E.G. Hallsworth and D.V. Crawford (eds.). Butterworths, London.

Razzaq, A. and A.J. Herbillon. 1979. Clay mineralogical trend in alluvium derived soils of Pakistan. *Pedologie* 1: 5-23.

Robert, M. and J. Berthelin. 1986. Role of biological and biochemical factors in soil mineral weathering. p. 453-495. In: Interactions of Soil Minerals with Natural Organics and Microbes. P.M. Huang and M. Schnitzer (eds.) Special Publication number 17. Soil Science Society of America, WI. USA.

Sawhney, B.L. 1972. Selective sorption and fixation of cation by clay minerals: A review. *Clays and Clay Minerals* 20: 93-100.

Scott, A.D. and S.J. Smith. 1966. Susceptibility of interlayer potassium in micas to exchange with sodium. *Clays and Clay Minerals* 14: 69-81.

Shakir, M.Y., M. Anwar and M. Rashid. 1994. Irrigation water as source of potassium. Proceeding of 4th National Congress of Soil Science. Soil Science Society of Pakistan. p. 399-404.

Sharma, B.D., S.S. Mukhopadhyay and J.S. Sawhney. 2006. Distribution of potassium fractions in relation to landforms in a Himalayan catena. *Archives Agronomy and Soil Science* 52: 469-476.

Sharpley, A.N. 1990. Reaction of fertilizer potassium in soils of different mineralogy. *Soil Science* 149: 44-51.

Simonsson, M., S. Andersson, Y. Andrist-Rangel, S. Hillier, L. Mattsson and I. Öborn. 2007. Potassium release and fixation as a function of fertilizer application rate and soil parent material. *Geoderma* 140: 188-198.

Simrad, R.R., C.R. De Kimpe and J. Zizka. 1992. Release of potassium and magnesium from soil fractions and its kinetics. *Soil Science Society of America Journal* 56: 1421-1428.

Singh, B. and W.T. Goulding. 1997. Changes with time in the potassium content and phyllosilicates in the soil of the Broadbalk continuous wheat experiment at Rothamsted. *European Journal of Soil Science* 48: 651-659.

Srivastava, S., T.R. Rupa, A. Swarup and D. Singh. 2002. Effect of long-term fertilization and manuring on potassium release properties in a Typic Ustochrept. *Journal of Plant Nutrition and Soil Science* 165: 352-356.

Waheed, M. 1998. Micaceous mineral weathering as affected by long-term fertilizer practices in sugarcane based cropping system. M.Sc. Thesis, Department of Soil Science, Barani Agricultural University, Rawalpindi.

Wang, J.G., F.S. Zhang, Y.P. Cao and X.L. Zhang. 2000. Effect of plant types on release of mineral potassium from gneiss. *Nutrient Cycling in Agroecosystems* 56: 37-43.