Chapter 2

Potassium mineralogy and its impact on crop production

2.1 Potassium-containing minerals in the soils of Punjab

The groups of minerals that have K in their structures; in order of the amount of K they hold; are micas, feldspars, vermiculite, allophone and other poorly ordered aluminosilicates, zeolites, smectites, chlorites and hydroxyl interlayered expansible phyllosilicates, kaolinite and halloysite, potassium-tarankite, and potassium-alunite (Schroeder, 1978; Sparks and Huang, 1985). Amongst them, occurrence of micas and feldspars is next to quartz in the coarse grains in the soils of Punjab. Almost all soils of Punjab have illite as most dominating minerals in clay size fraction, and it is considered a key group of minerals that are principally governing K dynamics in these soils (Sidhu, 1982). Smectite is a dominating mineral in clay fractions in salt-affected soils of Punjab, which has its origin from illite through losses of K and proton (Sehgal et al., 1974).

2.2 State of depletion of K from soils of Punjab and its consequences

Rice-wheat system in Punjab removes more than 300 kg ha^{-1} yr^{-1} of K from the top 0-15 cm of the surface soils (Yadvinder-Singh et al., 2004). In the absence of K-dressing, the rate of K- depletion in the long-term fertilizer experiment on maize-wheat cowpea (fodder) system at Ludhiana (Punjab) during 1970 through 1984 was 136 kg ha^{-1} (Singh and Brar, 1986), while during 1984 through 2004 it was 149 kg ha^{-1} (recalculated data of Brar et al., 2006). These data demonstrate chronological pace of increasing rate of depletion of potassium from soils. In other words, it implies that the rate of K depletion increases with the advancement of agricultural practices (with genetically advanced varieties, and with sophistications in tillage, fertilizer and water management), and might also be with the weathering of soil-minerals. If the average potassium reserve in these soils is calculated at 40 000 kg ha^{-1} and K-loss at the rate of 300 kg ha^{-1} yr^{-1}, then potassium might get completely exhausted by 125 years (Mukhopadhyay and Brar, 2006). The changes in the status of forms of potassium may be seen from this backdrop, and may be linked to the state of K-containing minerals and with the stability fields of soil minerals. Bharadwaj (1999) observed that the stability regions for the parent materials lie in the smectite regions for soils under agriculture and in the illite region for the soils under forestry in the soils of the

Punjab Himalayas. She found that the stability field at the steady state was in kaolinite region when either the soils were kept submerged or, they were slightly acidified, whereas in normal cases, it was mica region. This was observed in soils irrespective of the land uses (agriculture and forest). These observations indicate that the phase transformation processes are operational to the direction of kaolinite region. Apart from it, the magnitude of activities of silicic acid (H_4SiO_4) is considerably higher than could have otherwise been expected from neutral to slightly acidic soils. For, K management purposes, the observations show that if potassium depletion continues as it is now, and if potassium loss is not compensated in the soils of Punjab, slowly but surely, the soil-minerals (especially micaceous minerals) would weather to low activity clays, which would have serious consequences on crop productivity, environmental quality, and eco-system health. From the view point of laying of experiments involving K, the region is likely to show up to the response of K applications to the demonstrative level to the farmers with the passage of time, but it may be too late to reverse the land degradation caused by irrecoverable K depletion from K containing minerals. From the view point of the health of the eco-system, non-application of potassium, which leads to imbalances in soil-plant continuum is of serious global ecological concern in post 2nd World War agriculture and forestry (Maene, 1995; Bijay-Singh et al., 2004). The grave situation of negative K balance (Table 1), even when K was applied to rice-wheat system in predominantly micaceous (illite in clay fraction) soils of the intensively cultivated Punjab plain was reported by Yadvinder-Singh et al. (2004). In many soils in Punjab, minerals are exclusive supplier of K, and as a consequence potassium has been depleted with every harvest, and as produce from farm or forest fields' moves to consumer zones, soils of Punjab are left to starve. In the eco-system escribe, over-drafting of pedospheric potassium has disastrous consequences, like rapid opening-up of cleavage planes of K-containing minerals (Mukhopadhyay et al., 1992), loss of active cation holding sites, leaching of silicic acid, and narrowing of Si:O ratio; all of which lead to weathering, which is detrimental to life support system (Mukhopadhyay, 2005). In ecological perspective, K loss is related to a larger issue of loss of bases, because of its intrinsic association with them. In a practical sense, if K loss is not compensated or, bio-consumed K is not recycled back to soil, then soil pH is lowered towards acidity, and the situation might get spiraled into an ecological disaster without visible yield loss symptoms. In the coming decades, modern agronomic practices (e.g., use of carbon dioxide as fertilizer, precision irrigation and agriculture) may replace age-old practices in farming in Punjab, and thereby rate of loss of potassium from the soils of Punjab may get further accelerated. Some of our Q/I experiments confirm this fear (Mukhopadhyay et al., 1992).

Table 1. Negative K balance in a long-term rice-wheat experiment during 1988-2000 at the Punjab Agricultural University, Ludhiana. Soils were dominated by micaceous minerals (illite in clay fraction) [a]

Treatments	Input				Output		Balance (input – output)
	Inorganic	Organic	Other Sources [b]	Total	Total [c]	Loss [d]	
	kg ha $^{-1}$						
T1–Control; 0 N	600	0	1292	1892	2540	284	- 932
T2-Urea-N; 150 kg N ha^{-1}	600	0	1292	1892	3418	284	1810
T3-GM+Urea-N [e]	600	0	1292	1892	3407	284	1799
T4-WS+ Urea-N	600	732	1292	2624	3376	394	1146
T5-WS+GM+ Urea-N [e]	600	732	1292	2624	3406	394	1176
T6-FYM+ Urea-N	600	972	1292	2864	3254	430	-820
T7-FYM+GM	600	972	1292	2864	3677	430	1243

[a] Adapted from: Yadvinder-Singh et al. (2004) with modification.
[b] Other sources = irrigation + rain + seed
[c] Total uptake by rice and wheat.
[d] Loss is calculated as 15% of the total K input.
[e] Total N additions in T3, T5, and T6 were adjusted to 150 kg N ha^{-1} with urea. No inorganic N was applied to T7.

2.3 Soil changes induced by crop depletion of potassium

A perusal of data show that field crops alone depletes 581 560 000 kg K every year from the soils of Punjab, while total K addition is only 9 929 000 kg, which is equivalent to 1.7 percent of the loss (Brar, 1997). In light texture and low organic carbon soils the depletion of K from the soil was much faster in the absence of K supply either from ground irrigation water or K dressing through fertilizers (Brar and Singh 1995). To find out what happens to soils, especially to soil minerals, when such large-scale exhaustions occur, we conducted a quantity-intensity analysis (Q/I) with five surface soils. The soils were sampled from benchmark profiles of Gurdaspur (Agro-Ecological Sub-Region (AESR) II), Phillour (AESR III), Ludhiana (AESR IV; normal soils), Sangrur (AESR IV; salt-affected soils), and Faridkot (AESR V). In a screen-house experiment, soils were depleted of K by successive cropping till K deficiency symptoms appeared. The loss of K ranged from 0.8 to 6.1 g kg^{-1} (equivalent to 1600-12200 kg ha^{-1}) (Table 2). The large variation in the plant uptake of K in spite of same management practices and intensity of exhaustion by the same crops indicates that K uptake is a function of soils, or more preciously, it is a function of soil-minerals. The data

Table 2. Changes in forms of K in soils in Agro-Ecological Sub-Regions (AESR) of Punjab [a]

AESR	Available K			Fixed K			Total K		
	A	B	C	A	B	C	A	B	C
	g kg^{-1}		%	g kg^{-1}		%	g kg^{-1}		%
II	0.045	0.022	51.1	5.455	4.353	20.2	19.0	15.8	16.8
III	0.015	0.014	6.7	3.735	3.486	24.9	18.4	12.3	33.1
IV*	0.033	0.012	63.6	3.467	2.863	60.4	16.8	15.8	6.0
IV**	0.041	0.024	41.5	5.584	5.226	6.4	18.8	18.0	4.3
V	0.035	0.016	54.3	2.465	2.359	10.6	16.7	14.7	12.0

[a] Adapted from: Mukhopadhyay et al. (1992)
* Normal soil; ** (salt-affected soils)
A = original soils; B = K depleted soils; C = intensity of change (A-B)/A

showed that: (a) total K-removal by plants increased with increasing K-content in soils, which could be associated with abundance of K-containing minerals, (b) loss of K when scrutinized along with the changes in fixed-K, it was found that as long as mineral-bound pool is available, plants will keep on utilizing K from it by altering mineral skeleton, and (c) exchangeable K is a poor index to comprehend K supply mechanism in soils. A comparison of fixed K data between normal soils and salt-affected soils showed that smectite, a group of mineral known for their lack of interlayer sites where K can be in fixed form, is the driving clay minerals to control K supply mechanism in the salt-affected soils (Table 2). Mukhopadhyay et al. (1992) explained that presence of sites with variable binding strength; a property associated with micaceous minerals, attributed K desorption isotherms to Freundlich type under extreme K stress situation in the soils of Punjab, whereas under normal situation, it is expected to be of Langmuir type. In many soils, where crop response to applied K was found, K desorption isotherms were of Langmuir type. This explains why many soils of Punjab despite being depleted of K evince no significant increment in yield to crop in response of K application.

In another growth room experiment, six soil samples with > 80 percent sand were depleted of potassium through successive growth of crops till they attained K deficiency symptoms. The soils were analyzed by employing Q/I relationship in a batch equilibrium technique at 25^0 C (298 K), and mica and vermiculite were measured quantitatively (Tables 3 & 4). Due to loss of potassium, the content of vermiculite increased at the expense of micas (illite in clay), Q/I curves shifted upwards (data not given), and changes in free energy (ΔF) at no gain-no loss of ΔK_{ex} became more negative on cropping (Mukhopadhyay and Brar; unpublished data). The data imply that if K depletion from soils are not checked, illite would be altered to vermiculite, and many advantages (e.g., good tilth, non-expandable nature of micas in contrast to slight swell-shrink nature of vermiculite, which may tear off roots under water stress condition, retention of Mg^{2+} and thereby its supply to plants) of a natural soils may be lost for ever.

Table 3. Physical, chemical, and mineralogical properties in some benchmark soils of Punjab: Effect of cropping

Sample No.	Soil series	Sand	Silt	Clay	Texture	pH	EC	OC	CEC	Vermiculite (%)	
		---------- % ----------					$dS\ m^{-1}$	%	$cmol\ kg^{-1}$	Before Cropping	After cropping
1.	Tulewal	80.5	12.2	7.3	ls	8.3	0.21	0.27	6.52	4.53	6.46
2.	Tulewal	88.3	7.5	4.2	s	7.5	0.12	0.16	2.39	3.23	4.37
3.	Samana	80.8	10.0	9.2	ls	7.4	0.11	0.14	2.72	3.62	5.16
4.	Samana	88.8	6.8	4.4	s	7.7	0.21	0.05	3.26	3.00	4.29
5.	Fathepur	82.7	9.8	7.5	ls	7.7	0.14	0.16	5.87	5.37	5.87
6.	Fathepur	84.0	4.8	11.2	ls	7.8	0.21	0.36	5.54	4.63	6.24

Table 4. Effect of cropping on some Q/I parameters in some benchmark soils of Punjab

Sample No.	Soil series	Activity ratio at no gain no loss of ΔK_{ex}		ΔF	
		Before cropping	After cropping	Before cropping	After cropping
		$cmol^{1/2}\ kg^{1/2}$		$kJ\ mol^{-1}$	
1.	Tulewal	0.28	0.51	-31.5	-16.7
2.	Tulewal	0.37	0.52	-24.6	-16.2
3.	Samana	0.27	0.30	-32.4	-29.8
4.	Samana	0.26	0.56	-33.4	-14.4
5.	Fathepur	0.20	0.50	-39.9	-17.2
6.	Fathepur	0.20	0.44	-39.9	-20.3

2.4 Composition and electron micrograph of K-minerals of Punjab soils

The data on the elemental composition of alkali-feldspar and muscovite (Table 5) show remarkable similarities in the mineral grains in spite of the fact that the soils were drawn from different soil series of Punjab. There is little difference in the mineralogical make-up of soils of these series. Therefore, it could be inferred that the difference in the response to applied potassium in these soils arise because of differences in the weathering state of the K-containing minerals, especially of micas, rather than from their elemental composition or, mineralogical make-up of soils. Secondly, the content of K in muscovite ranged

Table 5. Elemental composition of alkali-feldspar and muscovite in some soil series of Punjab[a]

Soil series	Chemical composition	
	Alkali-feldspar	Muscovite
Samana	$K_{0.93}Na_{0.06}Ca_{0.01}Al_{1.01}Si_{2.99}O_8$	$K_{8.88}Na_{0.17}Ca_{0.20}Al_{18.99}Fe^{3+}{}_{0.28}Mg_{0.49}Si_{22.03}O_{20}(OH)_4$
Bhundri	$K_{0.94}Na_{0.05}Ca_{0.02}Al_{1.03}Si_{2.97}O_8$	$K_{8.78}Na_{0.06}Ca_{0.20}Al_{12.93}Fe^{3+}{}_{0.42}Fe^{2+}{}_{0.28}Mg_{0.31}Si_{22.17}O_{20}(OH)_4$
Ghabdan	$K_{0.94}Na_{0.05}Ca_{0.02}Al_{1.01}Si_{2.99}O_8$	$K_{8.82}Na_{0.50}Ca_{0.10}Al_{17.50}Fe^{3+}{}_{0.43}Fe^{2+}{}_{0.28}Mg_{0.74}Si_{22.13}O_{20}(OH)_4$
Bains-Awans I	$K_{0.94}Na_{0.05}Ca_{0.02}Al_{1.01}Si_{2.99}O_8$	$K_{7.99}Na_{0.35}Ca_{0.20}Al_{17.40}Fe^{3+}{}_{1.45}Fe^{2+}{}_{0.08}Mg_{0.55}Si_{22.89}O_{20}(OH)_4$

[a]Sample of surface soils; Figures represent percent composition.
Adapted from: Sidhu (1982) with some modification

from 7.99 to 8.88 percent (Table 5), which is lower than K content in the standard muscovite (10%). This implies a substantial loss of K from the interlayers of muscovite. It could happen only when layers open up.

Electron micrographs of coarse sand size mica grains (biotite and muscovite) illustrate irregular boundary along with broken planes and itch pits that are produced through dissolution (Fig. 1).The macrocrystals were platy, often perturbed with foreign microcrystals. The grains were strained, and at edges were marked with cleavage opening (Mukhopadhyay et al., 2008; unpublished data). Earlier Sidhu and Gilkesh (1971) opined that the mica grains of the surface soils of Punjab were regular in structure, and of fresh origin. The discrepancies of these two observations were perhaps because of advancements in electron microscopic resolution coupled with high magnification.

2.5 Agro-ecological sub-regions (AESR) of Punjab and soil mineralogy

Punjab is divided into six Agro-ecological sub-regions (AESR), which are described in Table 6 and illustrated in Fig. 2.

Mineralogical make-up of soils: In general, the soils of Punjab are dominated by quartz, micas (both muscovite and biotite), and feldspars (both plagioclase and orthoclase) in the decreasing order in the sand fractions, and small amounts of heavy minerals in the sand fractions in AESRs of I-IV (Mukhopadhyay and Datta, 2001). Amongst micas, muscovites was more abundant than biotites in semi-arid zone, and in reversed order in arid zone. Silt fractions resembled sand fractions in their mineralogical make-up. Illite is most

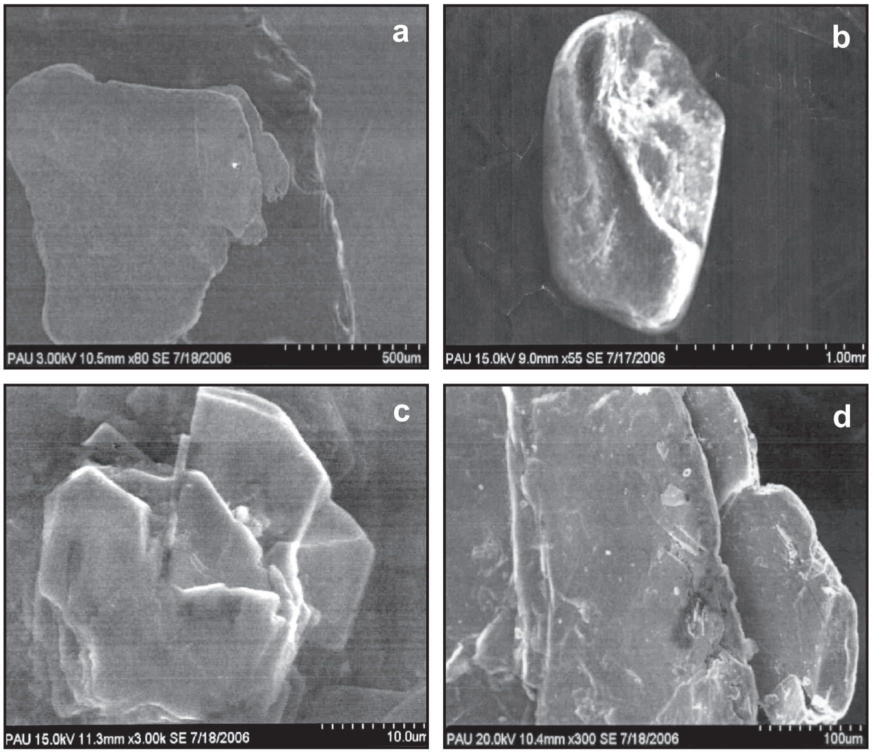

Fig. 1. Secondary electron image of mica grains separated from very coarse sand in the Agro Ecological Sub-Region II of Punjab. (a) Muscovite. Note thin platy psedohexagonal nature of the grain. The grain boundary is more regular than biotite. (b) A biotite grain. (c) Biotite image at an accelerated current. Note: Broken boundary, and exfoliated nature. Growth of rod shaped psedocrystal is evident. (d) A closer look at high accelerated current. Note: Opening of cleavage plain. Dissolutions pits are evident.

dominating minerals in clay fractions, followed by vermiculite. Apart from these, clays have various amounts of chlorite, smectite and kaolinite. Most soils of Punjab contain carbonate minerals, although their exact mineralogical configuration and nature of their solubility are not reported. X-ray diffractograms of clay samples of soils of Punjab invariably show broadening of 1.0 nm peaks towards low angle that suggest loss of interlayer K^+ from illite (Sidhu, 1982). A co-existence of illite-vermiculite phases in clays of the soils of the entire state indicate that the mineral phases are under K^+ loss regime, and prevalence of K^+-stress regime is in spite of K^+ incorporation through irrigation water, and crop residue, and fertilizer application, if any (Mukhopadhyay and Brar, 2006).

Table 6. Description of soils in Agro-ecological sub-regions (AESR) of Punjab

AESR	Description	Climate			Distinguishing Characters	Area (ha)
		Rainfall (mm)	Mean Annual Soil Temp.	Soil Moisture Regime		
I	Western Himalayas, subhumid (moist subhumid) with Length of Growing Period (LGP) of 180-210 days	1150-1320	20.4° C	Udic	The soils are moderately deep to very deep; well drained with excessive runoff; neutral to slightly alkaline (pH 6.5-7.8); and low in salt content (EC < 0.2 dS m^{-1}).	26393 (0.5 %)
II	Western Himalayas, subhumid (Dry subhumid / moist subhumid) with LGP of 150-180 days	900-1100	20-25° C	Ustic	The soils are moderately shallow to very deep; well drained with excessive runoff; gravelly, sandy to loamy sand; neutral to moderately alkaline (pH 6.7-8.5); and low in salt content (EC < 0.2 dS m^{-1}).	120690 (2.4 %)
III	Northern Plain, Dry subhumid, with alluvium derived soils, & LGP of 120-150 days	800-900	22° C	Ustic	The soils are generally stratified; very deep; well to excessively drained; sandy loam to loam and at some places sandy clay loam; slightly to strongly alkaline (pH 7.5-8.8); and low in salt content (EC < 0.2 dS m^{-1}).	303711 (6.0 %)
IV	Northern Plain, Semiarid, with alluvium derived soils, & LGP of 90-120 days	500-800	24° C	Ustic	The soils are very deep, well to moderately well drained; sandy loam to silty clay loam; slightly to strongly alkaline (pH 7.6-8.7); and low in salt content (EC < 0.54 dS m^{-1}).	3580457 (71.0 %)
V	Western Plain, Arid with Desert soils & LGP of 60-90 days	400-500	25-26° C	Aridic	The soils are very deep; some-what excessive to well drained; sandy; occur on very gentle to	957773 (19.0 %)
VI	Western Plain, Arid with Desert soils & LGP of <60 days	< 400	26° C	Aridic	moderate dune slopes; moderately to strongly alkaline (pH 8.3-8.6); EC is 0.13-0.19 dS m^{-1} with very low contents of OC (0.05-0.09%); and CEC 4.2-9.6 cmol kg^{-1}. In the interdunal soils, pH is 8.0-9.5; EC 1.2 dS m^{-1}, OC (only in surface) 0.20-0.75%; CEC 4.1-9.6 cmol kg^{-1}.	55450 (1.1 %)

LEGENDS

A11Cm6	Western Himalayas, subhumid (moist subhumid) 180-210 days
A11C(d/m)6	Western Himalayas, subhumid (Dry subhumid / moist subhumid) 150-180 days
N8Cd4	Norther plain, Dry subhumid, 120-150 days
N8D3	Northern plain, Semiarid, 90-120 days
M9E2	Western plain, Arid 60-90 days
M9E1	Western plain, Arid < 60 days

Fig. 2. Agro-Ecological Sub-Regions of Punjab (Adapted from Sidhu et al., 1995).

This scenario is alarming in view of the postulation of diversification from the present cereal based cropping system to fruits, vegetables and high-value crops. The soils that have principal provenance from the sedimentary and metamorphic rocks of the Himalayas have more muscovite than biotite in the coarse particle fractions, while soils that have provenance from both the rock systems of the Aravallis and the Himalayas have more biotite than muscovite in coarse loess materials. Biotite is known to release more potassium than muscovite (Plummer, 1918; cf. Rich, 1968). In soils that have both the species of micas (biotite and muscovite), release of K occurs from muscovite only when entire biotite-K source is depleted (Pal et al., 2001).

2.5.1 Location, geology and environmental setting of AESR I & II

Location and climate: The AESR I & II form a part of the western Siwalik Himalayas, and falls between 32°31′35″ to 31°N latitude and 75°18′45″ to 76°42′21″E longitude. It is (Fig. 2) bounded by the mountain state Himachal Pradesh on the north and the east, and by the Punjab plains on the south and the west.

The climate is sub-humid (moist/ dry). The rainfall varies from 990 to 1500 mm with mean annual rainfall of 1072 mm. Eighty per cent of rain is received during the three monsoon months (July through September) and most of the remaining during the winter (November through January) and there are two dry spells in between. There is considerable variation between the mean maximum (31.6° C in June) and mean minimum (13.7° C in January) temperatures. The mean annual air temperature (MAT) is 23.4°C.

2.5.2 Location, geology and environmental setting of AESR III & IV

Location and climate: The AESR III & IV form a part of the Indo-Gangetic plain bordering the Siwalik Himalayas on the north and Great Indian Desert on the south. It falls between 30°44′13″ to 32° N latitude and 74°28′08″ to 76°56′28″E longitude.

The climate is sub-humid (dry sub-humid to semiarid). The rainfall varies from 500 to 800 mm. Eighty per cent of rain is received during the three monsoon months (July through September) and most of the remaining during the winter (November through January) and there are two dry spells in between. There is considerable variation between the mean maximum (31.6°C in June) and mean minimum (13.7°C in January) temperatures. The mean annual soil temperature (MAST) is 24°C.

2.5.3 Location, geology and environmental setting of AESR V & VI

Location and climate: The arid region of Punjab is spread over from 73°50′37″ to 75°50′37″E longitude and from 29°33′09″ to 30°47′42″N latitude and covers 14510 km^2. The region is divided into two Agro-ecological sub-regions (AESR) *viz.* Western Plain, Arid with Length of Growing Period (LGP) 60-90 days and Western Plain, Arid with LGP < 60 days. The average terrace elevation is 222 m.

The region receives an annual mean rainfall of 300-500 mm, out of which > 80% is received from July through September. The variability in annual rainfall is more than 60 percent over the years, and rainfall in winter is erratic. The mean annual temperature is 32.10° C, mean summer temperature is 38.6 °C and mean winter temperature is 25.50° C. In general, summers are hot and winters are cool.

Land forms and mineralogy: Land is marked with terraces and dunes. There was no marked difference in the mineralogy of soils developed on different land form units. Quartz was the most abundant mineral in these soils and its content decreased with decrease in particle size. Both plagioclases and alkali feldspars were common in coarse fractions. Muscovite and biotite were present in the sand fractions. Illite was the most abundant mineral in the clay fraction of these soils. Other minerals present in clay fractions are kaolinite, smectite and chlorite (Sidhu 1982).

2.6 Potassium mineralogy in AESR I & II

In this region, the spatial distribution of minerals and potassium are function of landscape units (Tables 7 & 8). The clays are dominated by illite (46-65%), followed by smectite with small amounts of kaolinite, vermiculite, and chlorite. Illites are fresh, and thereby, they are capable of supplying K to plants. Similarly, the spatial distribution of potassium is governed by the land forms, as the operational intensity of factors and processes of soil formation vary with the land-forms (Sharma et al., 2006). The distribution of various forms of potassium has a strong bias with the mineralogical make-up of the soils.

Table 7. Semi-quantitative distribution of minerals in clay fraction of a Himalayan catena in Punjab [a]

Horizon	Depth (cm)	Illite (%)	Smectite (%)	Kaolinite (%)	Vermiculite (%)	Chlorite (%)
Pedon 1 (Landscape element: Shoulder)						
C2	36-66	46	17	10	12	15
Pedon 2 (Landscape element: Backslope)						
A	0-10	51	26	11	12	--
C2	30-70	54	28	12	6	---
C4	116-152	47	24	10	13	6
Pedon 5 (Landscape element: Footslope)						
Ap	0-20	54	20	11	--	15
Bw1	46-81	60	15	11	5	9
Pedon 6 (Landscape element: Toeslope)						
A	0-20	64	13	9	9	5
C2	40-96	65	10	7	9	9
C4	136-174	60	10	8	11	11
Pedon 7 (Landscape element: Toeslope)						
A	0-25	65	11	-	7	17
C2	40-65	61	9	-	20	10
C5	200-225	63	8	-	21	8
Pedon 11 (Landscape element: Recent flood plain)						
C6	129-141	66	9	9	12	4

[a] Adapted from: Deka et al. (1995)

Table 8. Semi-quantitative distribution of minerals in clay fraction in the soils of piedmont (District: Ropar) of the Punjab Himalayas [a]

Horizon	Depth (cm)	Illite (%)	Smectite (%)	Kaolinite (%)	Vermiculite (%)	Chlorite (%)
Pedon 1 (Landscape element: piedmont)						
A	0-20	51	23	14	7	5
Bw	69-92	49	22	15	12	2
C	135-150	61	12	16	9	2
Pedon 2 (Landscape element: Old filled up channel)						
Ap	0-13	49	32	3	14	2
Bw	51-75	58	25	4	10	3
Pedon 3 (Landscape element: Point bar complex)						
Ap	0-20	47	38	4	7	4
Bw1	46-81	41	49	5	1	4
Pedon 4 (Landscape element: Lower terrace)						
Ap	0-15	47	29	6	14	4
Bw	40-75	54	23	8	5	10
C	91-125	46	36	7	7	4
Pedon 5 (Landscape element: Recent flood plain)						
Ap	0-15	61	22	5	7	5
C	46-75	54	30	6	9	1
Pedon 6 (Landscape element: Sand bar)						
A	0-30	60	23	11	1	5
C	115-125	59	18	11	2	10

[a] Adapted from: Verma et al. (1994)

2.7 Potassium mineralogy in AESR III-VI

In the central and south-west Punjab, soils bear influence of sediments of both the Himalayas and the Aravallies. This zone experienced sediments brought by rivers, course change of rivers, especially the Satluj from west end of the state to central plains, and wind-rework of the earlier sediments. This zone is also sensitive to climate changes – four successive climate epoch in quick succession in the last 10 000 years. The loess material is particularly of common occurrence in south-west part (AESR V-VI). In general, biotite mica decreases and muscovite-mica increases from south-west to north-east. This has special bearing on potassium management because of two reasons: (i) coarse particles contribute to release of K, a phenomenon uncommon with most other nutrient ions, and (ii) higher release of K^+ from biotite-mica than muscovite-mica, because of shorter distance between K^+ and H^+ in biotite-mica than that in muscovite-mica.

Table 9. Distribution of potassium-containing minerals in some important soil series of AESR III & IV of Punjab [a]

Soil series	Muscovite [1]	Feldspars [1]	Biotite [2]	Illite [3]
	-----------------	----------------- %	-----------------	-----------------
Ladhowal	17-31	10-14	16-32	35-50
Nagar	20-50	8-16	23-60	51-57
Naura	15-40	6-23	10-35	60-66
Kalaran	5-15	20-25	Rare-frequent	-
Kotli	5-25	15-30	Rare-frequent	-
Samana	15-18	14-20	21-28	40-60
Ghabdan	16-20	14-18	16-23	35-45

[a] Adapted from: Sidhu (1982)
[1] In percentage of light sand, which is 95-98% of the total sand
[2] In percentage of heavy sand, which is 2-5% of the total sand
[3] In percentage of clay

As far as clay is concerned, illite (term commonly used for clay size mica) is a dominating mineral throughout Punjab, and perhaps both dioctahedral and trioctahedral species occur together (Sidhu, 1982). In some important soil series, Sidhu (1982) reported 35 to 66 percent illite in clay fraction (Table 9).

The soils of these regions also show that sand fraction is dominated by medium to very fine sand in sand separates, and light sand in specific gravity separates. Important K containing minerals in principal soil series in Punjab are muscovite and feldspar in light sand fraction (sp. gr. < 2.65) and biotite in heavy sand fraction. Their wide variation from series to series (Table 9) suggests that soil mineralogy could be most handy tool to decipher variation of K status and K response to plants. There is acute shortage of sufficient data on mineralogical make-up of the soils in Punjab. We strongly recommend that all future endeavors of K management experiments must be in conjunction with the K-mineralogy of soils.