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Morphological, Chemical and Mineralogical Characteristics of a Chronosequence of Soils on Alluvial Deposits in Pakistan

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ABSTRACT

A study was undertaken in three alluvial soil series namely, the Lyallpur, (old river terrace), the Sultanpur (sub-recent) and the Shahdara (recent) to investigate the morphological, chemical and mineralogical characteristics of a chronosequence of the soils. The results showed that the particle distribution was haphazard in the Shahdara series only. Clay contents increased from surface to sub soil with age. Silica-Oxide content increased from surface to lower horizons continuously in all the series. While, Fe_2O_3 and Al_2O_3 remained inconsistent. Calcium was not more readily leached from these materials than was magnesium. The loss of silica relative to sesquioxide was greater in the early stages of development except Shahdara series in early stages. In later stages of development, the loss of sesquioxide was greater than silica with continuous loss of bases. The sand and silt fractions of these soils have mixed mineralogy i.e. the mineral present in sand were quartz, feldspars and mica while silt fraction had chloride and kaolinite in addition to the minerals present in sand. The clay fraction (< 2 mm) had illite throughout in all the profiles. Smectite was more in Shahdara and it decreased with age. Vermiculite was absent while chlorite and kaolinite were present though in minor amounts in all the series.

Key Words: Morphology; Mineralogy; Soil Series; Chronosequence

INTRODUCTION

The mineralogy of the parent material has an impact on clay mineralogy of soil. As weathering proceeds, the clay content increases as a result of physical and chemical alteration of primary minerals. With further chemical changes, transformation may take place within the clay fraction of the soil. The type of clay minerals formed depends on the climatic conditions and the chemical environment within the soil. The general course of transformations is: Feldspar→ iIllite→ Vermiculite→ Montmorillonite→ Kaolinite→ Oxides of Fe and Al. Chlorite and illite represent younger, montmorillonite and vermiculite the intermediate and oxides the oldest state of weathering.

A number of studies related to the chronosequence revealed that with time, O.M. content increased, soluble salts, basic cations and $CaCO_3$ were leached and pH was decreased (Foss & Rust, 1962) while Campbell (1971) found that after initial accumulation of O.M., there was distinct trend of decreasing values with further passage of time. The Ca: Mg ratio narrows with increasing soil age because of more leaching of Ca compared to Mg (Parsons *et al.,* 1962). A decrease in CEC with increasing weathering and increase in clay content has also been noted (Brewer & Walker, 1969). Brinkman and Rafiq (1971) studied land forms and parent material and noted that the sediments in the plains of Pakistan were derived from a wide variety of rocks in the Himalyas and adjoining uplands and have given rise to three distinct age surfaces i.e. the recent (100 years old), the sub-recent (600-1000 years age) and the pliestocene 10^3 to $2x10^3$ years old. This paper describes the physical, chemical, morphological and mineralogical characteristics of a chronosequence of soils on alluvial deposits in Pakistan.

MATERIALS AND METHODS

The profiles of three soil series (Table I) were exposed at the selected locations and were described with the technical help of the soil survey staff, Lahore. The main morphological features of these series are given in Table II. Bulk soil samples were collected from AP, B and C horizons for physical, chemical and mineralogical analysis. The soil samples were air dried, crushed, passed through a 2 mm sieve and preserved.

Particles size analysis (Moodie *et al.*, 1959), O.M. and

Table I. Classification of soil series

Sr.No.	Series	Order	Family
1.	Shahdara	Entisols	Coarse-silty calcareous hyperthermic typic torrifluvent
2.	Sultanpur	Aridisols	Coarse-silty, mixed calcareous, hyperthermic, Fluventic Camborthid.
3.	Lyallpur	Aridisols	Fine-silty, mixed hyperthermic ustalfic Haplargid.

total nitrogen (Jackson, 1962) and mineralogical analysis (Jackson, 1964) were determined. The samples were dispersed in Na_2SO_3 solution and sand was separated by wet sieving, silt and clay by high-speed centrifugation and sedimentation. The sand, silt and clay fractions were studied for mineralogical analysis by X-ray diffraction by preparing mounts of sand, silt and clay was saturated with K and Mg solutions and then heated to 350 and 550°C. The total chemical analysis of the clay fraction was carried in a teflon-lined bomb according to the method described by Buckley and Cransten (1971).

RESULTS AND DISCUSSION

Morphological features. The main morphological features of the profiles (Table II) indicated that top soil colour and structure were uniform throughout the soil sequence but the sub-soil colour varied, structure ranged from depositional stratifications in the youngest soil to well developed structural aggregates in the oldest soil. Both the EC and pH of the surface soil had comparatively higher value in the youngest than in the other. Soil depth, horizon thickness and structural development increased and clay illuviation became pronounced with time. Gile (1966), Brinkman and Rafiq (1971) and Ahmed *et al.* (1977) also reported similar results.

Physical and chemical features. The distribution of soil particles i.e. sand, silt and clay (Table III) was haphazard in the various horizons of the Recent Shahdara series profile indicating a kind of stratification of the alluvial material. In the subrecent Sultanpur soil series, the clay content increased from 21 to 24% from surface to subsoil (66 mm). In the Lyallpur soil series, there was a continuous increase in the clay content from surface to subsoil upto 90 cm. The particle size distribution showed small changes in the various size fractions in the C horizon. The increase in the clay content of the B

Table II. Main morphological features of the soil series

Soil series	Age	Climate	Drainage	Microrelief	Main morphological features
Shahdara	Recent (late Holocene)	Semiarid and sub humid sub tropical centinental	Well drained	Level land	Moderately deep-to-deep well-drained, medium textured, calcareous soils without three horizons, subsoil are stratified.
Sultanpur	Sub recent	Semi arid sub tropical continental	Well drained	Level or smooth	Brown/ dark brown silt loam, massive, moderately calcareous Ap horizon underlain by a brown to dark brown silt loam, very weak coarse sub angular blocky, moderately calcareous B horizon underlain by a brown, very fine sandy loam and silt loam, massive, moderately calcareous C horizon which is usually stratified.
Lyallpur	Late pleistocene	-do-	-do-	-do-	Brown, silt loam, with weak sub soil structure very deep with distinct kankars in lower sub soil, well drained strongly calcareous

Table III. Physical and chemical analysis of soils

Horizon	Depth (cm)	EC_e dS m^{-1}	pH_s	$CaCO_3$ (%)	OC (%)	CEC C mol kg^{-1}	Clay (%)	Silt (%)	Sand (%)
SHAHDARA									
Ap	00 - 17	0.86	8.1	13	0.5	10.4	17	61	22
C1	17 - 26	0.90	8.1	11	0.2	6.0	8	70	22
C2	26 - 60	1.1	8.1	11	0.16	4.1	5	60	35
C3	60 - 67	1.3	8.2	14	0.23	9.0	15	70	15
C4	67 - 92	7.2	8.1	11	0.16	4.1	5	61	34
C5	92 - 102	9.5	8.0	14	0.23	9.2	20	70	10
SULTANPUR									
Ap	00 - 10	0.84	7.9	10	1.0	11.4	21	52	29
BW1	10 - 29	0.82	8.0	10	0.6	11.0	22	53	25
Bw2	29 - 66	0.94	8.1	10	0.3	11.1	24	61	15
2C1	66 - 84	0.7	8.0	11	0.2	6.0	7	50	43
2C2	84 - 110	1.12	7.9	11	0.2	6.0	7	70	23
2C3	110 - 118	1.1	8.0	14	0.31	10.0	21	70	9
LYALLPUR									
Ap	00 - 13	0.74	7.8	1.1	0.62	10.0	20	53	27
BAT	13 - 28	0.34	7.9	1.1	0.42	8.4	22	56	22
BT1	28 - 58	0.90	7.9	1.1	0.31	10.0	26	53	21
BT2	58 - 90	0.85	8.0	3.2	0.26	9.0	30	51	19
2BCK1	90 - 110	0.75	8.0	10.0	0.22	7.0	26	53	21
2BCK2	110 - 145	0.40	8.1	10.0	0.20	5.0	14	62	24

horizon with increasing soil age has been reported by Brewer and Walker (1969). Ahmed *et al.* (1977) also found clay illuviation only in the older members of some soil chronosequence as in this case.

The organic carbon was low (0.5%) in AP of the Shahdara series than the Sultanpur (1%) and Lyallpur (0.62%) series. Depthwise distribution of O.C. was irregular in recent series while a consistent decrease in the subrecent and the older soil series. Franzmier and Whiteside (1963) reported that O.M. accumulated in the soil with increasing development. Campbell (1971) also observed that after reaching a stable equilibrium in nature, it declined. In the present study, there was no consistent increase in O.M. with age. The possible reason for low O.M. in these soils may be high temperature, which promotes its rapid oxidation. $CaCO_3$ is an important index of the degree of a soil development. It is inconsistent in series under study. It decreased with soil age.

Mineralogical composition of the soils. The chemical analysis of the clay fraction indicated that SiO_2 was continuously increased from upper horizons to the lower horizons in all the series. The total Fe_2O_3 and Al_2O_3 remained inconsistent in all the profiles except Fe_2O_3 in the Shahdara series, which increased from upper to lower horizons. Fig. 1 shows the relative molecular ratio of CaO to MgO plotted as a function of depth with the ratio of the lowest horizon of each profile set at unity. The curves show that calcium is not more readily leached from these materials than is Magnesium. It is evident from the CaO/Al_2O_3 and MgO/Al_2O_3 data of molecular ratio (Table IV) that calcium and magnesium are not leached from the parent material during the development of the sola of these profiles. Sillica-allumina ratios for the three profiles are shown in Fig. 2. Comparing the youngest (Shahdara) with the oldest (Lyallpur) profile there is slight decrease in alumina with respect to silica in the A horizon with time. These ratios and the SiO_2/Al_2O_3+Fe_2O_3 relative ratios given in Table V indicated that the loss of silica relative to sesquioxide was greater in the early stages of development of sola except in Shahdara. In the next stage in the development of soils except Shahdara, the higher silica-sesqauioxide ratio for the A horizon reflects greater leaching of the sesquioxide with respect to silica with continued loss of

Fig.1. Relative ratio of Ca to Mg as a function of depth for these profiles

Fig. 2. Relative ratio of SiO_2 to Al_2O_3 plotted as a function of depth for three profiles

Table IV. Chemical composition (%) of clay fraction

Horizon	Depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Other
SHAHDARA									
Ap	00 – 20	45.2	23.2	10.0	1.4	2.4	3.1	0.17	14.53
C1	20 - 90	46.1	23.7	11.3	1.9	2.5	3.1	0.2	13.3
C2	90 - 120	46.1	23.0	11.4	1.1	2.5	3.16	0.2	12.54
SULTANPUR									
Ap	00 - 15	45.0	21.4	10.0	2.1	2.5	3.2	0.2	15.6
B2	15 - 75	48.5	21.1	9.5	0.8	1.9	3.58	0.2	14.42
C	97.5 - 120+	48.7	23.0	10.6	0.8	2.1	3.32	0.21	11.27
LYALLPUR									
Ap	00 - 20	45.0	21.0	12.4	1.1	1.9	2.86	0.17	15.57
B2	35 - 112.5	45.4	20.4	13.0	0.7	2.2	3.12	0.15	15.03
C1	150+	46.4	22.2	12.0	1.0	2.7	3.12	0.16	12.42

basis particularly calcium and accompanying decrease in pH from 8.1 in the A horizon of Shahdara series to 7.8 in the A horizon of Lyallpur series, marked losses of sesquioxide has occurred relative to silica losses. Jenny (1941) has pointed out that potassium and sodium are particularly sensitive criteria of leaching intensities as a result of weathering and soil formation. The Na_2O/Al_2O_3 and K_2O/Al_2O_3 ratios given in Table V showed some leaching of sodium and potassium, it is apparent that chemical alteration within the profiles as regards these elements are not very profound. The trend of K_2O/Na_2O molecular ratio given in Table V indicated greater loss of sodium than potassium with age reflecting a greater degree of weathering.

The sand and silt fractions of these soils have mixed mineralogy (Table VI) i.e. the minerals present in the sand fraction were quartz, feldspars and mica while in silt fraction in addition to these minerals there were chlorite and kaolinite. Akhter (1989) and Rahmat Ullah (1991) found that sand and silt fractions of alluvial and loessial soils of Pakistan are composed predominantly of quartz, mica, kaolinite, chlorite and feldspars. Calcite was present only in five series they studied. They further reported that there was no significant difference in the sand and silt fraction mineralogy attributable to the parent material or climatic conditions. Since the catchment area has wide variety of rocks, the alluvium has mixed mineralogy and so do the alluvium derived soils. Similar mixed mineralogy has been reported in soil developed upstream (Gupta & Awasthi, 1982). The occurrence of weatherable minerals (Feldspars, Biotite) as coarse grains indicate an early stage of the mineral weathering in the soils studied.

The results of X-ray differaction analysis of 2 mm clay fraction from surface and subsoil horizons from all the three soils are presented in Table VII for the Lyallpur, the Shahdara and the Sultanpur series, respectivley. The illite content was the same throughout the profile in all the series. Smectite was more in the Shahdara and it decreased with soil age. In the case of the Lyallpur series, smectite content increased in the C material. Vermiculite was absent while chlorite and kaolinite were present, though in minor amounts, in all the three series. Minerals in the clay fraction are subjected to weathering and transformation with soil development (Brewer & Walker, 1969). The chlorite and illite apparently represent the younger, the smectite and vermiculite, the intermediate; and the oxides, the oldest state of weathering (Franzmeier & Whiteside, 1963;

Table VII. Clay mineralogy of <2 μm fraction

*Soil series	Horizon	Illite	Smectite	Chlorite	Kaolinite
Shahdara	Ap	3	3	1	2
	C1	3	2	1	1
	C2	3	2	2	1
Sultanpur	Ap	3	1	2	2
	B	3	2	2	2
	C	3	2	2	2
Lyallpur	Ap	3	1	2	1
	B	3	1	2	1
	C	3	3	2	1

*= None of the soil series had vermiculite; 4= Dominant; 3= Major; 2= Minor; 1= Traces

Table V. Molecular ratios calculated from total chemical analysis data

Horizon	$SiO_2/(Al_2O_3+Fe_2O_3)$		CaO/Al_2O_3		MgO/Al_2O_3		Na_2O/Al_2O_3		K_2O/Al_2O_3		K_2O/Na_2O	
	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.
SHAHDARA												
Ap	1.36	1.02	0.06	1.20	0.10	0.91	0.007	0.78	0.13	0.93	18.24	1.15
C1	1.36	1.02	0.04	0.80	0.11	1.00	0.009	1.00	0.14	1.00	15.50	0.98
C2	1.34	1.00	0.05	1.00	0.11	1.00	0.009	1.00	0.14	1.00	15.80	1.00
SULTANPUR												
Ap	1.43	0.95	0.10	2.50	0.12	1.33	0.009	1.00	0.15	1.07	16.00	1.01
B2	1.59	1.06	0.04	1.00	0.09	1.00	0.010	1.11	0.17	1.21	17.90	1.13
C	1.50	1.00	0.04	1.00	0.09	1.00	0.009	1.00	0.14	1.00	15.81	1.00
LYALLPUR												
Ap	1.35	0.99	0.05	1.00	0.09	0.75	0.008	1.14	0.14	1.00	16.82	0.86
B2	1.36	1.00	0.03	0.60	0.11	0.92	0.007	1.00	0.15	1.07	20.80	1.07
C1	1.36	1.00	0.05	1.00	0.12	1.00	0.007	1.00	0.14	1.00	19.50	1.00

Table VI. Sand and silt mineralogy

Soil Series	Sand			Silt				
	Quartz	Feldspars	Mica	Quartz	Feldspars	Mica	Chlorite	Kaolinite
Shahdara	4	3	2	4	2	2	1	2
Sultanpur	4	2	2	4	2	2	1	2
Lyallpur	4	2	2	4	2	2	1	1

Jackson, 1964; Campbell, 1971; Brady, 1984). But in the present study the mineralogical variation of alluvial soils reflected the differences of their original material rather than that of pedogenic processes. So the loessial materials (alluviated) carry principally hydrated mica (illite) and smectite in association with chlorite and kaolinite.

CONCLUSION

The sediments in the chronosequence are derived from a wide variety of rocks in the Himalyas and adjoining uplands and these are very clear three types of surfaces i.e. recent, subrecent and Pleistocene. The sand fraction had quartz feldspar and mica and silt fraction had Chlorite and Kaolinite in addition to the above. The clay fractions had mixed mineralogy but dominant one was illite. Still more work is needed on the mineralogy of these soils.

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