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Distribution of Sodium in Relation to Development of Alkalinity in Some Soils of Central Punjab

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Abstract: Six alluvial soils developed on floodplains and terraces having different degree of development from semi-arid to sub-humid climate in Punjab were investigated for their physico-chemical properties, soil solution composition, and distribution of sodium. The soils from floodplains have immature profile (A-C), whereas from terraces have weak profile development (A-Bw-C). The soils are moderately to strongly alkaline having pH varying from 8.28 to 10.09. The soils having $CaCO_3$ accumulation had more alkalinity. The soluble sodium and exchangeable sodium had positive and significant correlation with pH, however, influence of former was more in floodplain soils (r = 743*) and that later in terrace soils (r = 866*). The exchangeable sodium dominated more in terrace soils than in floodplain soils. The ionic composition indicated $CaHCO_3$/$MgHCO_3$ and $NaHCO_3$ to be the dominant constituents of the soils. Sodium bicarbonate was mainly factor responsible for development of alkalinity in these soils. Study suggested that the soluble sodium could be responsible for higher pH in floodplain soils, whereas soluble and exchangeable sodium in terrace soils. The total sodium content was found to be associated with primary minerals in sand fraction rather than in clay fraction. A part of sodium seems to be contributed by weathering of Na-minerals in sand and silt fractions of the soils.

Key words: Alluvial soils, physico-chemical properties, sodium fractions.

The soils of central Punjab have developed on alluvial parent material deposited by the rivers of Indus system (Wadia, 1976). The accumulation sodium and sodium salts is common feature in alluvial soils having imperfect drainage especially in the drier regions (Barbour *et al.,* 2007). The poor land and water management are the main causes of sodium accumulation and development of alkalinity in soils. The alkali soils with preponderance of bicarbonate and carbonate of sodium are called sodic soils (Bhargava and Pal, 1981). Sodic soils have occupied about 3.77 Mha out of a 6.73 Mha of salt-affected soils in India (Sharma *et al.*, 2007). In Punjab, about 0.06 Mha of land is still under the problem of sodicity and salinity (Sharma *et al.,* 2009). The mechanism of sodium accumulation and in turn formation of alkali soils is associated with the release of sodium by weathering of alumino-silicates and subsequent formation of alkali carbonates or by use of poor quality of irrigation water (Bhargava, 1978; Abrol, 1982; Acharya and Abrol, 1991).

Sodium is considered to be highly mobile constituent and when accumulated in excess amounts, it causes problems in soils. The sodic soils are difficult to be brought under cropping due to toxicity of sodium, high pH and poor physical condition. Sodium occurs in water soluble, exchangeable and mineral matrix forms in soils and their contents vary in different soils. The reclamation technology of sodic soils is based on removal of active forms of water soluble and exchangeable sodium from surface soils. The presence of abundant sodium ions and precipitation of calcium increases in exchangeable sodium percentage (ESP) and in turn high pH (Vinayak *et al.*, 1981). Singh and Mishra (1994) ascribed the sodiumization of some Alfisols due to weathering of Na-rich minerals and subsequent accumulation of sodium in basin by run-off under differential wet dry sequence. In view of prevalence of alkaline reaction in alluvial soils of Punjab, the present investigation was undertaken to study the distribution of sodium in different fractions and its influence in development of alkalinity.

Materials and Methods

The study area forms the part of the Indus plain in central parts of Punjab extending

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between the latitudes of 30° 20′ and 31° 33′ north and longitudes of 74° 30′ and 76° 02′ east. The area is represented by flat level plains comprising the thick alluvial sediments having varied textural composition deposited during the Pleistocene to recent times by the rivers of the Indus system (Wadia, 1976). The soils of the area were examined for their site and profile characteristics by undertaking traverses and examining auger bores and exposed profiles. Two different geomorphic surfaces namely floodplains and terraces were identified on which these soils have developed. Along with auger bores several exposures of soils were studied for differentiation of soils. Six typical profiles (P1, P2, P3, P4, P5 and P6) varying in their physico-chemical characteristics were selected for detail study.

The study area with its inland and sub-tropical location is characterized by a continental, semi-arid to sub-humid climate. The area exhibits contrasting summer and winter seasons associated with kharif (Fall) and rabi (Spring) crops, respectively. The mean annual rainfall varies from 425 to 670 mm. About 70% of the annual rainfall is received during the monsoon period from July to mid-September. The water balance data suggested aridic and ustic moisture regimes for the area. The temperature pattern indicates January as the coldest month, with the mean maximum temperature ranging between 20 to 25°C and the mean minimum being less than 5°C. The mean temperature works to be 10 to 15°C. By contrast, June is the hottest month and the mean maxima touches 45°C while mean minima are about 20°C. The area has mean annual temp varying from 23.2 to 24.5°C and hence qualifying for hyperthermic temperature regime.

The various physico-chemical properties were determined following standard procedures. Particle size distribution was determined by pipette method (Day, 1965). The soil samples were fractionated into sand, silt and clay as per the procedures of Jackson (1979). The pH of 1:2 soil:water suspension was determined using Elico Model L110 glass electrode, whereas electrical conductivity of 1:2 soil/water suspensions was measured by using a solubridge. Organic carbon was determined by dichromate oxidation following rapid titration method of Walkley and Black (1934). Rapid titration method of Puri (1930) was used for estimation of calcium carbonate equivalent of soils. The rapid method for simultaneous determination of exchange capacity and exchangeable cations was applied for the soil samples collected from the profiles (Belyayeva, 1967). The composition of soil solution was determined in 1:5 soil water extract (Richard, 1954). Total elemental composition was determined by acid digestion (HF + $HClO_4$) of soil samples in platinum crucible at 200 to 250°C. The residue was dissolved in 6 M HCl and analyzed for elemental composition after suitable dilution (Hesse, 1994).

Results and Discussion

Morphological characteristics

Site characteristics of the study are described in Table 1. The soils have developed on alluvium in two different physiographic positions, viz. floodplains and alluvial terraces. The slope of the ground is nearly level to very gentle having maximum slope up to 3%. Generally, drainage and permeability of the soils are moderate and low due to low relief, cementation and finer texture of the soils. The soils from floodplains (P1, P2 and P3) exhibit immature profile (A-C), whereas slils from terraces (P4, P5 and P6) have weakly developed profile having horizon sequence A-Bw-C. The soils from floodplains are very deep, poor to moderately drained, and medium in permeability. The parent materials of floodplain soils, particularly in P1, appear

Table 1. Site characteristics of the study area

Profile	Parent material	Physiography	Relief	Slope (%)	Drainage	Permeability
P1	Alluvium	Floodplain	Low	1-3	Poor to moderate	Medium
P2	Alluvium	Floodplain	Low	1-3	Poor to moderate	Medium
P3	Alluvium	Floodplain	Low	1-3	Poor to moderate	Medium
P4	Alluvium	Alluvial terrace	Normal	0-1	Moderate	Low
P5	Alluvium	Alluvial terrace	Normal	0-1	Moderate	Low
P6	Alluvium	Alluvial terrace	Normal	0-1	Well	Low

to be stratified as texture varies from loam through sandy loam and silt loam to sand. The P2 soil, however, exhibited more uniform silt loam texture except sandy loam texture in C2 horizon. The soils though generally contain free calcium carbonate in the profiles but lime nodules were almost absent in P2 soil. Light brownish gray to olive brown matrix color in lower horizons of P1, P2 and P3 soils and presence of mottles indicated their fluctuating drainage condition. Except in P1 soil, floodplain soils do not contain calcium carbonate nodules.

The soils from terraces (P4, P5 and P6) are very deep, moderate to well drained and low in permeability. The surface horizon is dark brown, whereas subsurface horizons show dark yellowish brown to light olive brown suggesting relatively better drainage condition than floodplain soils. The terrace soils exhibit relatively uniform parent material having invariably silt loam texture throughout the profile except loam texture in surface horizon of P4 soil. All the terrace soils except P6 show reaction with HCl indicating their calcareous nature. Accumulation of appreciable amounts of calcium carbonate was observed in subsurface horizons of P4 soil. The terrace soils frequently contain calcium carbonate nodules. A thick layer of lime nodules was observed below 50 cm depth in P5 soil. The P6 soil though free of calcium carbonate shows presence of few iron manganese nodules below 64 cm depth.

Physico-chemical characteristics

The sand, silt and clay contents of these soils vary from 12.6 to 88.6%, 7.4 to 72.6% and 4.0 to 25.8%, respectively (Table 2). The sand content was highest in P1 soil (weighted mean = 44.1%) and lowest in P5 soil (weighted mean = 18.4%), whereas the silt content was highest in P5 soil (weighted mean = 63.0%) and lowest in P1 soil (weighted mean = 42.8%). The highest content of clay was present in P4 soil (weighted mean = 22.4%) and lowest in P2 soil (weighted mean = 9.3%). The particle size distribution suggested relatively coarser nature of floodplain soils (P1, P2 and P3) and finer nature of terrace soils (P4, P5 and P6). The soils of the study area are moderately alkaline to strongly alkaline in reaction having pH varying from 8.28 to 10.09 in different horizons. Relatively lower pH ranging from 8.28 to 8.67 (weighted mean = 8.44) was observed in P6 soil and higher pH ranging from 9.20 to 10.09 (weighted mean = 9.91) was observed in P1 soil. The surface horizon of the soils had relatively lower pH than underlying horizon (except in P6) may be due higher organic matter content. Electrical conductivity ranges from 0.06 to 1.30 dS m^{-1} in different soils. The electrical conductivity was low in P3 soil (weighted mean = 0.19 dS m^{-1}) and higher in P1 soils (weighted mean = 0.68 dS m^{-1}) indicating normal to slight salinity in these soils. Organic carbon content ranged from 0.02 to 0.65% in different horizons of the soils having higher content in the surface horizon (0.44 to 0.65%) and lower content in subsurface horizon (0.02 to 0.32%). The P2 soil of floodplains showed the highest content organic carbon (weighted mean = 0.24%), whereas P5 soil from terrace showed the lowest content (weighted mean = 0.13%).

The soils contain calcium carbonate both as dispersed particles and as segregated nodules within the profile. Except P6 soil, all soils contained free calcium carbonate suggesting their calcareous nature. Calcium carbonate in floodplain soils varied from nil to 13.8%, whereas in terrace soils it varied from nil to 19.5% suggesting relatively low content in the former. Distribution pattern with depth suggested generally low concentration of calcium carbonate in surface horizon and accumulation in lower horizons suggesting some eluvial/illuvial processes associated with pedogenesis in the soils. The P6 soil seems to have undergone complete leaching of calcium carbonate. The floodplain soils were almost lacking in calcium carbonate nodules suggesting time a limiting factor for redistribution of calcium carbonate and formation of nodules. Cation exchange capacity varied from 4.44 to 14.21 cmol (p^+) kg^{-1} having the lowest in P3 soil (weighted mean = 5.32 cmol (p^+) kg^{-1}) and the highest in P5 soil (weighted mean = 12.41 cmol (p^+) kg^{-1}). The terrace soils showed relatively higher cation exchange capacity as compared to floodplain soils primary due to finer texture of the former. Exchange complex dominated with calcium plus magnesium followed by sodium and potassium.

Classification of soils

The soils were classified following the criteria of Soil Taxonomy (Soil Survey Staff, 1999). The soils of floodplains (P1, P2 and P3) were qualified for Entisols on account of

Table 2. Physical and chemical characteristics of the soils

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2)	EC (dS m^{-1})	$CaCO_3$* (%)	OC (%)	CEC {cmol (p^+) kg^{-1}}
				Profile P1 (Soil from floodplain)					
Ap	0-18	46.0	39.8	14.2	9.20	0.49	8.7	0.48	7.49
AC	18-45	38.7	46.1	15.2	9.92	0.49	5.3	0.24	7.64
C1	45-84	59.4	30.0	10.6	9.92	0.57	Nil	0.11	5.92
C2	84-108	27.2	56.6	16.2	10.08	0.63	6.3 (ca)	0.03	8.69
C3	108-143	16.4	66.6	17.0	10.09	1.30	9.0 (ca)	0.12	8.59
C4	143 +	88.6	7.4	4.0	9.97	0.33	Nil	0.02	4.44
Wt. mean		44.1	42.8	13.1	9.91	0.68	4. 7	0.15	7.18
				Profile P2 (Soil from floodplain)					
Ap	0-19	25.7	65.9	8.4	8.53	0.39	Nil	0.65	6.29
C1	19-43	27.4	63.2	9.4	8.94	0.23	7.1	0.26	6.28
C2	43-65	60.3	33.5	6.2	8.93	0.18	5.4	0.14	5.90
C3	65-93	25.8	64.0	10.2	8.88	0.20	10.8	0.16	6.31
C4	93-109	21.9	64.3	13.8	9.02	0.24	13.8	0.17	7.55
C5	109+	18.6	72.6	8.8	8.93	0.23	8.7	0.11	6.28
Wt. mean		30.4	60.3	9.3	8.87	0.24	7.6	0.24	6.38
				Profile P3 (Soil from floodplain)					
Ap	0-17	39.9	50.7	9.4	8.91	0.21	5.5	0.50	5.88
C1	17-25	37.5	52.5	10.0	9.48	0.18	4.7	0.15	5.21
C2	25-37	34.7	57.0	8.3	9.51	0.19	3.7	0.14	4.93
C3	37-62	41.5	48.5	10.0	9.53	0.20	7.3	0.13	5.36
C4	62-105	42.0	48.3	9.7	9.48	0.19	7.8	0.11	5.21
Wt. mean		40.4	50.0	9.6	9.40	0.19	6.6	0.18	5.32
				Profile P4 (Soil from terrace)					
Ap	0-19	33.3	48.7	18.0	8.58	0.24	4.0	0.54	7.99
Bk1	19-53	21.8	57.2	21.0	9.05	0.23	15.1	0.08	8.82
Bk2	53-81	16.5	59.1	24.4	8.95	0.33	15.2	0.06	9.30
Bk3	81-102	17.6	60.0	22.4	9.02	0.29	19.5 (ca)	0.09	9.46
BCk	102-130	16.3	58.3	25.4	8.90	0.38	16.4 (ca)	0.12	10.8
Wt. mean		20.5	57.1	22.4	8.92	0.29	14.5	0.15	9.33
				Profile P5 (Soil from terrace)					
Ap	0-15	24.6	61.4	14.0	8.76	0.34	1.5	0.53	13.85
Bw1	15-37	21.5	57.9	21.6	9.13	0.26	1.5	0.19	14.21
Bw2	37-50	19.9	58.5	21.6	9.24	0.21	1.9	0.11	13.29
Bw3	50-79	18.7	59.8	21.5	9.18	0.23	13.8 (ca)	0.03	13.33
Bw4	79-106	20.8	58.1	21.1	9.23	0.23	14.4 (ca)	0.05	11.53
BC	106-136	12.6	70.2	17.2	9.28	0.19	4.8 (ca)	0.11	13.34
C	136-162	15.4	71.2	13.4	9.27	0.25	8.2 (ca)	0.07	8.44
Wt. mean		18.4	63.0	18.6	9.18	0.24	7.6	0.13	12.41
				Profile P6 (Soil from terrace)					
Ap	0-18	35.7	51.9	12.4	8.67	0.40	Nil	0.44	6.75
Bw1	18-28	30.2	51.6	18.2	8.50	0.55	Nil	0.32	8.91
Bw2	28-64	21.9	54.7	23.4	8.28	0.35	Nil	0.14	9.50
Bw3	64-88	24.3	50.7	25.0	8.36	0.18	Nil (fe)	0.17	10.52
Bw4	88-112	21.9	52.3	25.8	8.40	0.14	Nil (fe)	0.12	10.93
C	112-133	22.6	56.0	21.4	8.65	0.06	0.8 (fe)	0.09	10.62
Wt. mean		24.9	53.2	21.9	8.44	0.26	0.1	0.19	9.70

* (ca) and (fe) indicate horizon having $CaCO_3$ and Fe-Mn nodules, respectively.

their immature profile with development no diagnostic horizon. These Entisols do not have a lithic, or paralithic contact within 25 cm depth, have a slope of less than 25%; and have an irregular decrease in content of organic carbon from a depth of 25 cm to 125 cm, and hence classified as Fluvents. The water balance data show ustic moisture regime of all the soils, as these remain dry for 90 cumulative days and moist for 180 days during the year. Because of being ustic moisture regime, the soils were classified as Ustifluvents at great group level. The floodplain soils do not find any place in specific subgroup, hence distinguished as Typic Ustifluvents. The soils of alluvial terraces (P4, P5 and P6), however, showed weak profile development as indicated by presence of cambic subsurface diagnostic horizon. These soils, hence, were qualified for Inceptisols. The ustic moisture regime differentiated them as Ustepts. The soils (P4) having calcic horizon with its upper boundary within 100 cm of the mineral soil surface were identified as Typic Calciustepts and other Ustepts (P5 and P6) with no defined features were classified as Typic Haplustepts.

Composition of soil solution

The composition of soil solution was determined in terms of presence of Na^+, K^+, Ca^{2+} + Mg^{2+}, CO_3^{2-} and HCO_3^-. Among the different cations, Ca^{2+} + Mg^{2+} together dominated over Na^+ and K^+, whereas HCO_3^- was the principal anion in soil solution (Table 3). A perusal of the data on soluble ions reveals sodium concentration ranging from 0.21 to 4.94 meq L^{-1}, whereas potassium from 0.02 to 0.33 meq L^{-1}. The soils invariably contain no carbonate ions except in one sample of P1 soil. Absence of carbonate suggests moderate alkalinity of the soils (Bohn *et al.,* 1985). The carbonate ion, if any, might have exhausted in the precipitation of calcium and magnesium carbonate in the soils. The presence of free calcium carbonate in the soils supports the same fact. Studies have reported that the development of sodicity in soils initiates with formation of pedogenic $CaCO_3$ (Pal *et al.,* 2000, 2009). The ionic composition suggested $CaHCO_3$/$MgHCO_3$ and $NaHCO_3$ as the dominant salt constituents in these soils. Kelley and Cummins (1921) illustrated, that a much greater amount of sodium is adsorbed on the exchange complex, when soils are treated with Na_2CO_3 as compared to NaCl and $NaNO_3$. The absence of sodium carbonate may be one of the reasons for relatively lower ESP of the soils (Table 3). The soils P1 showed some amounts of carbonate ion in soil solution that may be reason for high pH, but not enough for higher exchangeable sodium percentage.

Like exchangeable sodium percentage, the soluble sodium percentage shows the relative abundance of sodium compared to other cations in soil solution. The soluble sodium percentage ranged from 3.98% to 46.36% with highest in P1 soil (weighted mean = 30.81%) and lowest in P6 soil (weighted mean = 5.46%). The soluble Na^+ content is relatively lower as compared to Ca^{2+} + Mg^{2+} in all the profiles indicating that these soils have not undergone sufficient sodium accumulation capable of replacing calcium and magnesium from the exchange complex (Vinayak *et al.,* 1980). Sodium exhibits relatively lower affinity for clay than other cations, therefore proportion of sodium to other cations as expressed as soluble sodium percentage must be well above 50% for its appreciable adsorption on exchange complex (Seatz and Peterson, 1968). The exchangeable sodium ranges from 0.14 to 2.31 cmol (p^+) kg^{-1} having the highest in P5 soil and the lowest in P3 soil. The terrace soils showed relatively higher exchangeable sodium compared to the floodplain soils (Fig. 1).

Total sodium in size fractions and soil

Among the different particle size classes, the clay fraction invariably contained relatively lower content of total sodium, whereas the sand fraction had higher total sodium in all the soils (Table 4). Relatively higher content of sodium in the sand fractions indicates that it mainly occurs in primary minerals, which is present in appreciable amount in coarse fraction of the soils. Earlier studies also reported presence of plagioclase, including albite in sand fraction of the Punjab soils (Raj-Kumar, 1998). Singh and Mishra (1994) found labradorite a common Na-bearing mineral responsible for sodiumization of alluvial soils of Bihar. The total sodium content in the sand, silt and clay fractions varied from 0.60 to 1.85%, 0.75 to 1.70% and 0.25 to 1.05%, respectively. In the sand fraction, the highest total sodium content was observed in P2 soil (mean = 1.49%) and the lowest content in P6 soil (mean = 1.28%). The highest and lowest total sodium in the clay

Table 3. Distribution of soluble ions and extractable bases in the soils

Depth (cm)	Soluble ions (meq L^{-1})				Extractable bases {cmol $(p^+)kg^{-1}$}				ESP
	K^+	Na^+	$Ca^{+}+Mg^{+}$	SSP*	HCO_3^-	K^+	Na^+	$Ca^{+}+Mg^{+}$	
Profile P1 (Soil from floodplain)									
0-18	0.14	1.63	4.0	28.25	4.0	0.07	0.22	7.20	2.9
18-45	0.18	2.21	4.0	34.58	6.0	0.09	0.35	7.20	4.6
45-84	0.06	1.65	7.0	18.94	5.0	0.06	0.26	5.60	4.4
84-108	0.02	2.61	3.0	46.36	2.0 (4.0)#	0.19	0.50	8.00	5.8
108-143	0.54	4.94	8.0	36.65	8.0	0.19	0.40	8.00	4.7
143 +	0.05	2.89	10.0	22.33	8.0	0.21	0.43	3.80	9.7
Wt. mean	0.18	2.74	6.2	30.81	5.6	0.13	0.36	6.69	5.0
Profile P2 (Soil from floodplain)									
0-19	0.33	0.44	7.0	5.66	6.0	0.05	0.24	6.00	3.8
19-43	0.14	0.44	6.0	6.69	2.0	0.04	0.24	6.00	3.8
43-65	0.09	1.29	11.0	10.42	8.0	0.10	0.20	5.60	3.4
65-93	0.07	0.21	5.0	3.98	6.0	0.05	0.26	6.00	4.1
93-109	0.08	0.35	6.0	5.44	2.0	0.06	0.29	7.20	3.8
109+	0.07	0.24	4.0	5.57	2.0	0.06	0.22	6.00	3.5
Wt. mean	0.13	0.49	6.5	6.26	4.5	0.06	0.24	6.08	3.8
Profile P3 (Soil from floodplain)									
0-17	0.18	1.41	7.0	16.41	6.0	0.26	0.15	5.47	2.6
17-25	0.12	1.65	5.0	24.37	5.0	0.26	0.14	4.81	2.7
25-37	0.08	0.76	4.0	15.70	4.0	0.34	0.15	4.44	3.0
37-62	0.06	0.65	6.0	9.68	5.0	0.43	0.17	4.76	3.2
62-105	0.14	0.54	6.0	8.08	4.0	0.34	0.17	4.70	3.3
Wt. mean	0.12	0.82	5.8	11.92	4.6	0.35	0.16	4.81	3.0
Profile P4 (Soil from terrace)									
0-19	0.12	0.59	11.0	5.04	4.0	0.09	1.10	6.80	13.8
19-53	0.06	0.78	11.0	6.59	4.0	0.12	1.30	7.40	14.7
53-81	0.08	0.76	3.0	19.79	4.0	0.10	1.20	8.00	12.9
81-102	0.09	0.73	8.0	8.28	4.0	0.06	1.20	8.20	12.7
102-130	0.12	0.61	12.0	4.79	4.0	0.10	1.30	9.40	12.0
Wt. mean	0.09	0.70	9.0	7.15	4.0	0.10	1.23	8.00	13.2
Profile P5 (Soil from terrace)									
0-15	0.06	3.41	8.0	29.73	6.0	0.18	1.27	12.40	9.2
15-37	0.08	3.48	5.0	40.65	8.0	0.32	2.29	11.60	16.1
37-50	0.04	1.70	5.0	25.22	6.0	0.18	2.31	10.80	17.4
50-79	0.02	1.50	9.0	14.26	4.0	0.17	1.96	11.20	14.7
79-106	0.03	1.44	3.0	32.21	2.0	0.13	1.40	10.00	12.1
106-136	0.04	1.57	8.0	16.34	2.0	0.14	2.00	11.20	15.0
136-162	0.03	1.44	5.0	22.26	2.0	0.18	1.86	6.40	22.0
Wt. mean	0.04	1.96	6.2	24.82	3. 9	0.18	1.87	10.36	15.1
Profile P6 (Soil from terrace)									
0-18	0.13	0.56	5.0	9.84	4.0	0.28	0.47	6.00	6.9
18-28	0.18	0.44	6.0	6.65	4.0	0.32	0.59	8.00	6.6
28-64	0.12	0.29	6.0	4.52	4.0	0.15	0.55	8.80	5.8
64-88	0.05	0.35	6.0	5.47	5.0	0.13	0.59	9.80	5.6
88-112	0.04	0.55	9.0	5.74	6.0	0.12	0.81	10.00	7.4
112-133	0.16	0.44	9.0	4.58	6.0	0.41	0.81	9.40	7.6
Wt. mean	0.11	0.39	6. 9	5.46	4.8	0.21	0.64	8.85	6.6

* Soluble sodium percentage; # value within bracket is CO_3^{2-}.

Table 4. Distribution of total sodium in size fractions and whole soil

Horizon	Depth (cm)	Soil texture	Total sodium (%)			
			Clay	Silt	Sand	Soil
			Profile P1 (Soil from floodplain)			
Ap	0-18	Loam	0.50	1.50	1.40	1.40
AC	18-45	Loam	0.60	1.45	1.40	1.50
C1	45-84	Sandy loam	0.65	1.60	1.50	2.05
C2	84-108	Silt loam	0.60	1.15	1.50	1.50
C3	108-143	Silt loam	0.70	1.20	1.45	1.10
C4	143 +	Sand	0.60	1.55	1.60	1.35
Mean	-	-	0.61	1.41	1.48	1.52
			Profile P2 (Soil from floodplain)			
Ap	0-19	Silt loam	0.45	1.15	1.40	1.90
C1	19-43	Silt loam	0.35	0.85	1.40	1.00
C2	43-65	Sandy loam	0.30	0.75	1.85	1.25
C3	65-93	Silt loam	0.50	1.15	1.50	1.25
C4	93-109	Silt loam	0.40	1.10	1.40	1.30
C5	109+	Silt loam	0.45	1.25	1.40	1.50
Mean	-	-	0.41	1.04	1.49	1.34
			Profile P3 (Soil from floodplain)			
Ap	0-17	Silt loam	0.40	1.15	1.25	1.33
C1	17-25	Silt loam	0.30	1.25	1.35	1.48
C2	25-37	Silt loam	0.45	1.15	1.45	1.63
C3	37-62	Loam	0.50	1.25	1.40	1.63
C4	62-105	Loam	0.45	1.20	1.40	1.63
Mean	-	-	0.44	1.20	1.38	1.57
			Profile P4 (Soil from terrace)			
Ap	0-19	Loam	0.60	0.90	1.25	1.25
Bk1	19-53	Silt loam	0.65	1.05	1.45	1.90
Bk2	53-81	Silt loam	0.75	1.55	1.40	1.60
Bk3	81-102	Silt loam	1.05	1.05	1.50	1.60
BCk	102-130	Silt loam	0.80	1.05	1.20	1.55
Mean	-	-	0.77	1.12	1.36	1.62
			Profile P5 (Soil from terrace)			
Ap	0-15	Silt loam	0.50	1.70	1.50	1.45
Bw1	15-37	Silt loam	0.35	1.30	1.50	1.40
Bw2	37-50	Silt loam	0.35	1.45	1.55	1.30
Bw3	50-79	Silt loam	0.25	1.05	0.60	1.45
Bw4	79-106	Silt loam	0.40	0.80	1.10	1.15
BC	106-136	Silt loam	0.30	1.15	1.40	1.30
C	136-162	Silt loam	0.30	1.25	1.40	1.40
Mean	-	-	0.35	1.24	1.29	1.34
			Profile P6 (Soil from terrace)			
Ap	0-18	Silt loam	0.75	1.25	1.35	1.65
Bw1	18-28	Silt loam	0.45	1.10	1.25	1.40
Bw2	28-64	Silt loam	0.30	1.50	1.45	1.70
Bw3	64-88	Silt loam	0.30	1.50	1.20	1.10
Bw4	88-112	Silt loam	0.45	1.15	1.20	1.25
C	112-133	Silt loam	0.55	1.25	1.20	1.20
Mean	-	-	0.47	1.29	1.28	1.40

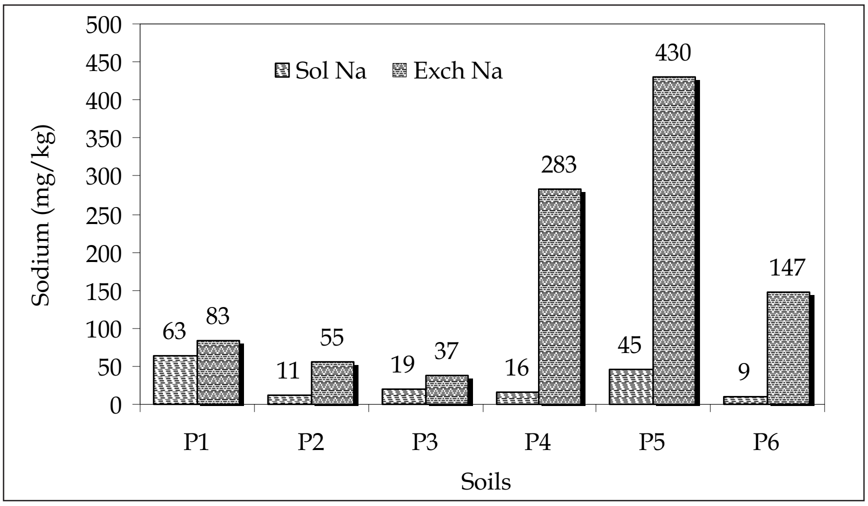

Fig. 1. Soluble and exchangeable sodium contents in different soils.

fraction was observed in P4 (mean = 0.77%) and P5 (mean = 0.35%) soils, and in the silt fraction in P1 (mean = 1.41%) and P2 (mean= 1.04%) soils, respectively (Fig. 2). Relatively higher content of total sodium in sand fraction of the floodplain soils and lower in the terrace soils suggest more weathering and release of sodium from the later soils.

The total sodium content in the soils ranges from 1.00 to 2.05% with the highest content in P4 soil (mean = 1.62%) and the lowest in P2 and P5 soils (mean = 1.34%). The distribution of total sodium in soils probably is influenced by the total content of sodium in the size fractions and their proportion in the respective soils. The total content of sodium in P1 and P3 soils probably had the influence of total sodium in sand and clay fractions, respectively.

Factors influencing alkalinity

The cation exchange capacity was mainly controlled by clay fraction of the soils. Exchange complex dominated with Ca^{2+} + Mg^{2+} followed by Na^{+} and K^{+}. The exchangeable Ca^{2+} + Mg^{2+} content varied from 3.80 to 12.40 cmol (p^{+}) kg^{-1} with the highest in the P5 soil (weighted mean = 10.36 cmol (p^{+}) kg^{-1}) and the lowest in P3 soil (weighted mean = 4.81 cmol (p^{+}) kg^{-1}). The exchangeable Na^{+} varied from 0.14 to 2.31 cmol kg^{-1} having the highest in P5 soil (weighted mean = 1.87 cmol (p^{+}) kg^{-1}) and the lowest in P3 soil (weighted mean = 0.16 cmol (p^{+}) kg^{-1}). The exchangeable sodium showed much closer relationship and affinity with CEC (r = 0.585*, 655*). The exchangeable sodium percentage (ESP) values ranged from 2.6 to 22.0%, and generally had low ESP below 15% in these soils.

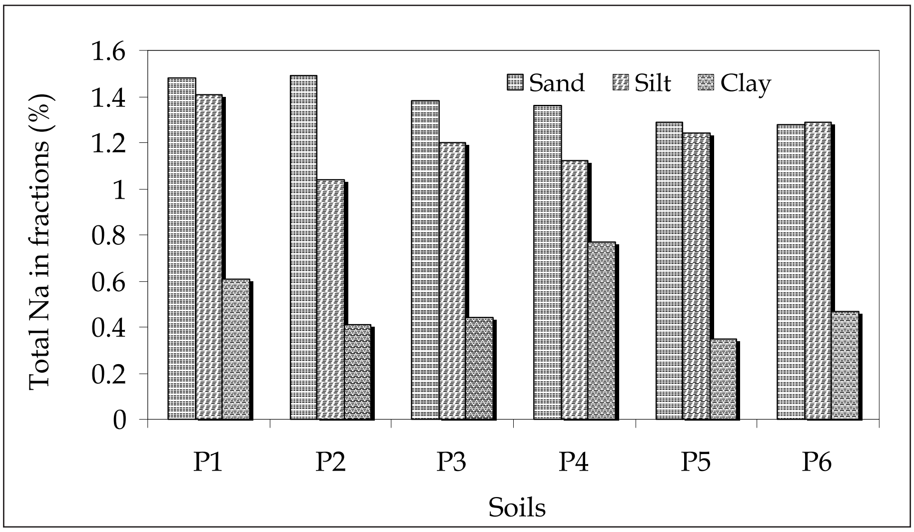

Fig. 2. Total sodium content in different size fractions of the soils.

Table 5. Correlation coefficient determined among various soil properties

Parameter	Clay	pH	EC	CEC	Soluble Na^+	Soluble $Ca^{2+}+Mg^{2+}$	SSP*	Soluble HCO_3^-	Exch Na^+
Floodplain soils									
Sol Na^+	0.426	0.743*	0.841*	0.426					
Sol $Ca^{2+}+Mg^{2+}$	-0.518	-0.059	0.056	-0.327	0.248				
SSP*	0.616*	0.770*	0.677*	0.551*	0.825*	-0.220			
Sol HCO_3^-	-0.112	0.319	0.369	0.012	0.618*	0.612*	0.397		
Exch Na^+	0.419	0.582*	0.627*	0.585*	0.646*	0.036	0.631	0.352	
ESP	-0.160	0.518	0.271	-0.016	0.488*	0.342	0.337	0.417	0.788*
Terrace soils									
Sol Na^+	-0.327	0.504*	-0.038	0.731*					
Sol $Ca^{2+}+Mg^{2+}$	0.140	-0.162	-0.180	-0.019	-0.194				
SSP*	-0.251	0.620*	-0.032	0.598*	0.874*	-0.564*			
Sol HCO_3^-	0.278	-0.284	-0.172	0.398	0.373	0.081	0.182		
Exch Na^+	-0.080	0.866*	-0.275	0.655*	0.678*	-0.077	0.683*	0.043	
ESP	-0.220	0.855*	-0.207	0.216	0.429	-0.038	0.500*	-0.225	0.865*

Critical value of r = 0.455 at 5%.

The soils from terraces showed relatively higher exchangeable sodium percentage, whereas the floodplain soils had the lower exchangeable sodium percentage. It is reported that problems of alkalinity and sodicity are more pronounced in fine-textured soils than in coarse-textured soils (Brinkman, 1988; Chhabra, 1996).

Correlation coefficient indicated significant positive correlation of soluble sodium with exchangeable sodium (r = 646*, 678*) in both the soils (Table 5). The soluble sodium and exchangeable sodium showed significant positive correlation with pH. The impact of soluble sodium on soil pH was evident more in floodplain soils (r = 0.743*), whereas that of exchangeable sodium (r = 0.866*) in terrace soils. It appears that sodium bicarbonate is the main factor which is responsible for variation in soil pH. It is a known fact, that increase in HCO_3^- and CO_3^{2-} ions in soil solution cause increase in OH^- ions and so does the rise in pH (Brady and Well, 2002). Presence of sodium carbonate in detectable amounts in one of the horizon of P1 soil may possibly be reason for its higher pH. The total sodium content of clay fractions had no significant effect on soluble sodium and exchangeable sodium. However, soluble sodium showed somewhat poor relationship with total sodium of silt possibly due to more susceptibility of silt to weathering and release of sodium than clay, which represent more stable fraction. It appears that sodium could partly be contributed by weathering of Na-bearing minerals in sand and silt fractions. Zade (2010) in his study found a relation between the total Na-content of soil and soil separates with exchangeable sodium percentage in formation of sodic soils of Indo-Gangetic plains and Vertisols of Purna valley.

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