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GENESIS OF SOME ARID SOILS OF RAJASTHAN AND THEIR POTENTIALITIES FOR USE

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Soils in the vast tracts of land which form part of the Thar Desert and lie in the arid zone of Rajasthan have remained inadequately studied. A large part of this area is lying fallow because of low rainfall and lack of irrigation facilities. These are known to be productive, and proposals are on hand to bring in irrigation waters to these areas. It was considered useful to make detailed studies of some of these soils so as to assess their likely behaviour under irrigation.

An area in Ganganagar District to the north-west of Rajasthan, was chosen and a number of profiles studied representing two physiographic units, one of which representing the Desert plain and the other the Ghaggar plain. In this paper one profile representing the former unit and another the latter unit are discussed. From a study of these soils it was found that these soils are alkaline in reaction, calcareous, low in organic matter content, base saturated and siliceous. The clay minerals of these soils are also siliceous with predominence of illite. The observations indicate less intense weathering conditions under high temperature which are commensurate with the climatic characters of the area.

The soils, while being generally free from salts in the surface layers, have high salt-content in the substrata with or without high exchangeable sodium content, and the subsoils also have poor drainage, intense management measures to overcome these limitations are necessary when irrigation is introduced. It will be necessary to carry out detailed surveys before irrigation is introduced so as to delineate the different types of soils which occur in an intricate pattern over the area, so that correct use of each of the soils can be recommended for adoption.

INTRODUCTION

It has been generally recognized that soil is the ultimate product resulting from the integrated effects of living matter and climate acting upon parent material as conditioned by relief over periods of time. Thus the trend of soil formation in any area depends upon the nature of combination of these various agencies, which are commonly recognized as the soil-forming factors. The soils of arid zone, because of the peculiar conditions prevailing in these regions, could be expected to fall within a number of groups because of the varied factors operating therein. The arid zones, which are characterized by low precipitation, excess of temperature, greater evaporation than precipitation, xerophytic type of vegetation and so on, could give rise to varied groups of soils, depending upon the variations in such other factors as parent material and topography. Scanty information is available on the genesis and classification of the arid soils in general, and those of Rajasthan in particular. An appreciation of these facts prompted us to undertake the study of the pedogenic processes in progress in such areas and the classification of soils.

Such studies assume even greater importance when soils in such arid areas are to be put to productive use through introduction of irrigation. The various genetic characteristics of soils such as texture, structure, organic matter content, induration, *p*H, cation exchange capacity, etc., singly or in combination, have direct bearing on the productivity of the soil. Hence information collected on these soils has great utility especially at the present time when emphasis is being laid on better exploitation of these resources which are either lying unutilized or only partially so.

In the arid regions such studies are of special significance as these involve utilization of the waters for effective and efficient irrigation facilities. When this happens, the soil-moisture regime is altered from a dry to a humid state. Experience about introduction of such changes, both in this country and abroad has shown that detailed information about soils and irrigation is essential to make such irrigation enterprise a success. Indiscriminate use of water has brought about soil deterioration and failure in many aspects of the irrigation projects. Such considerations compel studies on the soils of the arid regions of Rajasthan where over 1.45 million hectares has not been fully exploited because of aridity and which could become productive after irrigation waters are made available.

LOCATION OF AREA STUDIED

With these considerations in view, a study was taken (Godse & Govinda Rajan, 1967) on soils of the parts of the arid region of Rajasthan, which will be under the command of the Bhakra and Rajasthan Canal systems. The area selected for these studies is located in the south-western part of Ganganagar District. The area comprises of two physiographic subdivisions, viz. (i) an alluvial fan, and (ii) an aeolian plain. Six profile sites in these areas were selected, divided equally between the two physiographic regions. Soils were collected from these profiles and their properties investigated to study the genesis of the soils derived under arid climate, to classify them into appropriate groups and to assess their suitability for irrigation purposes.

The soils were collected from the Suratgarh and Anupgarh tehsils of Ganganagar District, situated between longitude 73° and 75° East and latitude 28° 30′ and 29° 50′ North.

Climate

The total annual rainfall of the area is around 240 mm while the mean monthly temperature varies from 37.5°F in January to 95°F in June. January is the coldest month, while June is the hottest. The mean monthly rainfall of Suratgarh in the vicinity of the area studied is as follows:

Average of 44 *Years* (*in mm*)

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
7.00	9.50	7.25	9.00	6.25	24.75	67.25	63.75	31.25	4.0	0.0	4.75

Total annual rainfall : 240.2 mm.

Mean monthly temperature for the Area (in °F)

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
57.5	62.5	74.0	84.0	92.5	95.0	92.5	90.0	88.0	80.0	69.0	60

The rainfall distribution over the area is of the monsoon type, of which 75% of the total precipitation is received during the three summer months of July, August and September. The remaining quantity is received during the rest of the year, excepting the month of November when there is no rain. The total annual rainfall is low.

Further calculations on the effectiveness of precipitation which is helpful for understanding the processes of pedogenesis indicate that in accordance with the Thornthwaite's climatic classification termed Precipitation Effectiveness Index, the overall value of the index for the whole year adds up to about 7. This is considerably lower than the minimum limit of 16 proposed for aridity in this classification. Hence on this basis it can be stated that the area studied has an arid climate.

Geology and Physiography in Relation to the Soils

The soils under investigation are derived from the deposits of a mixed nature which are either related to the alluvium of the river Ghaggar or the sandy plains of the Thar Desert. The desert region in the area of present study is constituted of two physiographic subdivisions, namely (i) the 'pat' section, and (ii) Ghaggar plain (Pithawalla, 1952). The 'pat' section (meaning flat section) covers parts of Sind, Khairpur, Jodhpur, Bhawalpur, Bikaner, etc., and extends northwards where the influence of south-west monsoon is not significant. These areas are covered over by sandy hills which rise to not more than 300 ft or so, and lie within a rugged terrain. In between the sand-hills there are hollows — a flat terrain in which rain waters collect.

The Ghaggar plain comprises of a large number of dry beds and ancient channels, now waterless and abandoned, but flanked by continuous ridges of sand hills. The beds show fine loamy soil lying between light sandy areas on either side.

Vegetation

The vegetation consists of the typical xerophytic trees and shrubs which characteristically occur over western Rajasthan. *Prosopis cinnareria, Acacia senegal, Acacia arabica, Salvodora ovoides, Zizyphus rotundifolia, Calotropis procera, Cassia auriculata,* among others, are common. The grasses include *Cenchrus catharticus, Panicum antidotale* and *Aristide adscencionis.*

Description of the Soils

Three profiles each in the (i) alluvial region, and (ii) aeolian deposit area, were collected. Details in regard to one of these profiles which is typical of each of the two types of terrain described, are given below.

(I) Profile over alluvial parent material

Location : Suratgarh farm, Block No. 2. Field No. RPM 1 (under Bhakra Canal Command, Ganganagar Dt., Rajasthan)

Elevation : 177 metres above M.S.L.

Physiography and relief : Flood plain, concave relief, 1% slope. Imperfectly drained, permeability slow to very slow and moisture is present below 75 cm. No indication of alkalinity or salinity, Stones—nil

Horizon No.	Depth (cm)	Description
1	0-17	Very pale brown (10 YR 7/3 dry, 10 YR 5/3 b·own moist), loam, weak, fine subangular blocky, soft, friable and non-sticky, moderately permeable. Strong effervescence, *p*H 8.2, gradual and smooth boundary.
2	17-45	Very pale brown (10 YR 7/3 dry, 10 YR 5/3 brown moist), clay loam moderate fine sub-angular blocky, slightly hard, friable and slightly sticky, moderately slow permeability, strong effervescence, *p*H 8.75 gradual boundary.
3	45-78	Pale brown (10 YR 7/3 dry, 10 YR 5/3 brown moist) silt loam, weak fine subangular blocky, soft, friable and non-sticky, very slow permeability, strong effervescence, *p*H 9.0, diffuse boundary.
4	78-122	Very pale brown (10 YR 7/3 dry, 10 YR 5/3 brown moist) silt loom, weak fine subangular blocky, soft, friable and non-sticky, very slow permeability, strong effervescence, *p*H 9.0, clear and smooth boundary.
5	122+	Pinkish grey (7.5 YR 6/2 dry, 7.5 YR 5/4 brown moist) silty clay loam, moderate fine subangular blocky, slightly hard, friable and slightly sticky, very slow permeability, slight effervescence, *p*H 9.15.

(II) Profile collected over the desert plains : The profile was located in a flat shallow basin surrounded by low sand hills not more than 3 inches higher than ground level. Lime content shows an increase with depth, maximum accumulation being in the last horizon. The first horizon appears to be a layer of recent wind deposit.

Location : In village Udasar, Anupgarh Tehsil, under Rajasthan Canal Command area, Dt. Ganganagar.

Elevation : 171 meters above M.S.L.

Parent material : Mixed sandy deposit in desert basin, concave relief with 0-1% slope.

Vegetation: Grassland with very sparse grass and a few shrubs

Drainage : Imperfectly drained, ground water very deep, soils moderately permeable in upper two horizons and slow to very slow permeability below

Salt or alkali : Occasional white patches of salt deposits in surrounding area

Horizon No.	Depth (cm)	Description
1	0-8	Very pale brown (10 YR 8/4 dry, 10 YR 5/4, yellowish brown moist), fine sand, single grain, loose, and non-sticky, rapid permeability, slight effervescence *p*H 8.4, abrupt boundary
2	8-35	Pale brown (10 YR 6/3, dry, 10 YR 5/3 brown moist) sandy loam, very weak fine granular, soft, very friable and non-sticky, moderate permeability, strong effervescence, *p*H 8.5, clear and smooth boundary
3	35-80	Light yellowish brown (10 YR 6/4 dry, 10 YR 5/4 yellowish brown moist) loam moderate fine angular blocky, slightly hard, friable and slightly sticky; slow permeability, violent effervescence *p*H 8.8, diffuse boundary
4	80-110	Light yellowish brown (2.5 Y 6/4 dry 2.5 Y 5/4 light olive brown moist) loam, moderate fine subangular blocky, slightly hard, friable and slightly sticky, slow permeability, violent effervescence, *p*H 9.2 clear and smooth boundary
5	110	Pale yellow (2.5 Y 7/4 dry, 2.5 Y 6/6 olive yellow moist) with 2.5 Y 8/6 yellow mottles, silt loam, massive, hard, slightly firm, sticky and plastic, slow permeability, violent effervescence, *p*H 9.0

RESULTS AND DISCUSSION

The analytical data in respect of the soils described in the above two profiles are given in Tables I and II.

The first profile represents non-saline soils developed over alluvium of the Ghaggar river. Its texture varies from loam to clay and the clay content rises from the first horizon to the second horizon and then declines. The silt content also shows an increasing trend with depth. The coarse sand fraction is less than 1% throughout, while the fine sand varies from 24.54 to 47.88%. Carbonate content also increases with depth The *p*H increases from 8.2 to 9.15 thereby indicating increase in alkalinity with depth. The distribution of clay bears no relationship to illuviation since the magnitude of differences in different horizons is too wide to have resulted from such a pedogenic process in this arid climate. This is possibly due to stratification of different deposits and not truly of genetic origin.

The second profile which has developed over the sandy desert plain is representative of soils that have light-textured surface soils and medium-textured sodic subsoils. The surface is loamy sand which becomes loam and silt loam in the lower horizons. The clay content which is only 4% in the first horizon increases irregularly till it is 23.65% in the last horizon. It is obvious that processes of eluviation and illuviation have been in progress in these soils. The uppermost horizon is possibly an overburden, the real profile starting from the second horizon. The silt content increases from 0.9% in the surface to 33% in the lowest horizon. The coarse sand fraction is very small and more or less uniform while fine sand constitutes the major fraction.

TABLE I

Mechanical composition and physical properties

Depth (cm)	*p*H (1 : 2.5)	Conductivity (1 : 2 extract in mmhos/cm	$CaCO_3$ equiv.	Organic C (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Porosity (%) (Volume basis)	Water holding capacity % (Wt. basis)	Moisture equiv. (Wt. basis)	Hydraulic conductivity (cm/hr)
Profile I												
0—17	8.2	0.34	1.24	0.14	0.86	47.9	24.9	22.9	47.98	37.6	19.3	0.303
17—45	8.75	0.54	1.47	0.11	0.49	26.9	21.8	47.3	54.81	47.5	24.2	0.033
45—78	8.9	0.35	4.01	0.08	0.68	35.6	26.2	31.9	46.60	39.1	22.9	0.005
78—122	9.0	0.55	2.62	0.05	0.97	45.5	30.2	18.4	48.44	39.9	19.7	0.014
122+	9.15	0.66	1.94	0.05	0.84	24.5	40.4	30.9	50.55	42.8	31.1	0.0018
Profile II												
0—8	8.4	0.08	1.70	0.14	0.65	91.9	0.9	4.0	35.88	25.1	3.91	4.590
8—35	8.5	0.18	4.24	0.15	0.48	79.8	6.3	8.4	35.96	24.4	7.50	1.330
35—80	8.8	0.33	7.23	0.10	0.54	70.8	6.5	14.2	37.2	26.7	11.55	0.023
80—110	9.2	0.31	6.08	0.06	0.35	69.8	11.3	11.4	39.9	27.6	14.09	0.035
110 +	9.0	0.54	22.89	0.08	0.22	19.1	33.0	23.7	48.6	38.3	25.78	0.027

TABLE II

Chemical composition

Depth (cm)	Soil (on oven dry basis %) SiO_2	R_2O_3	SiO_2/R_2O_3	CaO	MgO	K_2O	Clay fraction (% on oven dry basis) SiO_2	R_2O_3	SiO_2/R_2O_3	CaO	MgO	K_2O	C.E.C. M.e./100 g clay
Profile I													
0—17	70.78	17.67	8.48	3.37	1.61	2.49	47.25	36.75	2.36	1.02	1.18	4.09	42.2
17—45	66.94	20.74	6.55	2.08	0.82	2.92	46.87	37.13	2.31	1.81	1.06	4.30	44.0
45—78	66.34	18.69	6.88	3.47	0.87	2.81	46.81	37.60	2.32	0.59	0.74	5.23	40.6
78—122	70.17	18.11	7.65	2.63	0.81	2.50	46.59	37.80	2.29	0.45	0.86	4.95	39.0
122 +	64.72	21.15	5.45	2.63	1.34	2.97	46.2	38.2	2.26	1.30	1.34	4.56	38.8
Profile II													
0—8	76.56	13.26	10.9	4.85	1.30	1.93	47.15	33.60	2.66	0.75	2.26	4.70	38.0
8—35	74.10	13.95	9.83	4.82	1.56	2.19	46.68	35.52	2.56	1.07	2.96	5.02	35.5
35—80	66.55	14.60	8.64	8.51	1.86	2.38	48.76	36.15	2.45	0.89	1.90	4.95	34.7
80—110	61.25	14.10	8.25	11.06	2.92	2.42	46.06	34.72	2.52	1.08	4.03	4.86	33.7
110 +	47.70	18.95	4.77	12.33	4.75	2.98	47.30	34.85	2.60	1.57	3.62	5.45	32.1

The carbonate content also increases, being nearly 23% in the last horizon. The *p*H value rises gradually down the profile. The conductivity value shows that salt content increases with depth.

Porosity, which is around 50%, shows a distinct relationship with the texture of the soil — fine textured soils having higher porosity than those with coarser texture. These soils, which have a higher clay content compared to the second profile, indicate a better capacity to store water for use by crops. Moisture equivalent, which is a measure of capillary porosity and in its turn related to clay content, is higher in the first profile compared to the second one where the soils are lighter textured. Hydraulic conductivity, which is a measure of the readiness with which soils transmit water, shows wide variations. Standards have been drawn up to grade the soils on the basis of hydraulic conductivity. According to these standards the first profile has moderate hydraulic conductivity in the surface which becomes very slow and extremely slow down the profile. While permeability is satisfactory in the surface layers, it becomes very different in the substrata to have satisfactory drainage. The second profile shows certain peculiarities in that its conductivity diminishes steadily down the profile While permeability is rapid to moderate in the surface horizons, it is very slow beyond the third horizon, and as a result the artificial drainage is also slow. In these horizons the slow permeability appears to be the combined effect of the relatively finer texture of the soil combined with the high percentage of exchangeable sodium.

The chemical composition of soils reveals the nature and extent of weathering and provides valuable information regarding the soil forming processes including mobilization of various constituents in the profile during soil formation. The silica content of the first profile varies between 70.78 and 64.72% while that of the second profile decreases from 76.5 in the surface to 47.7% in the fifth horizon. The data show that in both the cases the argillic horizons have lower silica content. The silica/sesquioxide ratio shows significant variations both within the profiles and between them. In the first profile the ratio varies from 5.45 and 8.48 while in the second one it ranges from 4.77 to 10.9. A scrutiny of the SiO_2/R_3O_2 ratio of clay fractions, however, indicates that these are narrower than those of the soils and more or less same for all samples. The silica-sesquioxide ratio of the soils shows wide variations, while those of the clay fractions do not, indicating translocation of clay in the profiles. This is confirmed by observations of the morphology of these profiles as well as the data on mechanical composition.

The CaO content in these soils shows a peculiar trend in distribution. While in the first profile the distribution is more or less uniform, in the second one, while being of somewhat higher concentration, it shows an increase down the profile. This could be due to downward movement of lime with the rain water. This situation can happen even under arid conditions as has been suggested by Robinson (1949), that even though the total precipitation in desert regions is low, it is erratic in nature and the rainfall received in the rain storms may be enough to produce the hydromorphic effects. The variations in MgO content in general follow that of CaO in the two soils.

The potash (K_2O) content of these soils in general is high and this could be due to considerable amounts of orthoclase feldspars in the sand fractions of the soils as reported by Gupta (1958) and also due to the clay minerals present in these soils which contain K_2O to the extent of 5%.

Nature and Constitution of the Clay Minerals

Clay fraction is the most reactive component of the soil and is mainly responsible for the various physico-chemical properties like moisture retention, nutrient retention, potassium fixation, plasticity, permeability and, above all the base exchange phenomenon. SiO_2 is the major content in the clay fraction of both the soils (Vide Table II) and is around 47%, being more or less uniform with the profiles also. Thus, it may be said that all the clay samples have uniformly equal silica content. The sesquioxides constitute the next abundant fraction in all the clay samples. The sesquioxide content, however, shows some small variations within the profile.

Significant information of value in distinguishing different types of clay minerals is given by the molecular SiO_2/R_2O_3 ratios. The ratio of the clay fractions in both the soils is more than 2.0 and ranges between 2.26 and 2.66. According to Robinson (1949) clays with this ratio of 2 or more are siallitic, and consist of minerals of 2 : 1 lattice type, such as montmorillonite and illite. Hence these clays contain minerals of the 2 : 1 lattice type and they belong either to the montmorillonite group or the illite group or both.

The cation exchange capacity of the clay samples ranges from 32.1 to 41.0 per 100g of clay. The values obtained are above the kaolinite type and below the minimum capacity of montmorillonite, slightly above the maximum limit of attapulgite and almost entirely within the limits of the illite type of clay minerals. Taking into consideration the silica sesquioxide ratios also, the possibility of kaolinite and attapulgnite minerals is eliminated. Since these values are too low to suggest presence of montmorillonite type of minerals, one is led to the conclusion that illite is the major constituent of these clay minerals admixed with possibly small amounts of montmorillonite.

The calcium (CaO) content of the clay samples shows variation within narrow limits. The same is the case with magnesium (MgO) content. In the first profile it is around 1% while in the second one it is in the range of 2 to 4%. Presence of magnesium as a constituent of 2 : 1 lattice type clay mineral is well accepted. In the crystal lattice it occurs as the main cation, replacing aluminium in the octahedral positions.

Potassium (K_2O) content of the clay samples is high and ranges from 4 to 5%. The amount of K_2O in clay is an indication of hydrous mica or illite to the extent of over 90%. Hence the evidence collected indicates that the clay is mainly of the illitic type.

Theory of Diagenetic Origin from Marine Sediments

According to one theory, the area of the desert region of Rajasthan formed part of the sea floor. As the climatic conditions underwent a change and aridity set in over the area, the sea got evaporated and the sediments of the sea floor gave rise to the desert deposits. The desert deposits can thus be looked upon as of marine origin, and if this is accepted, then the genesis of illite type of clay minerals can be explained.

According to Grim (1953) in the marine enviornment which is alkaline, there is no leaching and the water contains a good deal of dissolved alkalies and alkaline earths. These environmental conditions favour formation of montmorillonite or illite type of clay minerals. In the absence of K, magnesium brings about formation of montmorillonite but if potassium is present, illite is formed. Since sea-water contains considerable amounts of potassium, the genesis of illite in marine sediments is a natural consequence. Correns *et al.*(1937), Dietz (1941), Bramlette and Bradley (1940) have reported that illite constitutes the predominant clay mineral in marine sediments. Thus, if it is accepted that the desert deposits of Rajasthan are of marine origin, illite, as the clay mineral in the soils, is the natural result.

Classification according to 7th Approximation System

From a study of the characteristic horizons of the two soils, it is seen that the first soil situated on the alluvial plains cannot be considered to be having argillic or natric horizons, because the horizons are stratified and not formed from pedogenic processes. It can be placed under order Entisol, suborder Ustent and great group Natric orthustent. The second profile can be classified under Aridisols and since the profile has an ochric epipedon between 8 and 35 cm of the profile and an argillic horizon between 38 and 80 cm, it can be classed under suborder Argid. Since it also has a Natric horizon which is also in an argillic horizon at the great group level, it can be placed as Natrargid.

Assessment of the Soil Properties for their Behaviour under Irrigation

Introduction of irrigation in unirrigated land is known to bring in a number of problems like salinity, alkalinity, water-logging and consequent soil deterioration. Past experience has shown the need for proper study of the soils proposed for irrigation and to make dependable forecasts on the behaviour of the soils to irrigation and also to bring out details about methods for remedeying the adverse effects that are likely to develop. Among the soil properties which are considered important from irrigation point of view are : (a) Permeability and related properties that influence movement of water through soils such as texture, structure, exchangeable sodium percentage, organic matter and induration; (b) Available water content and other factors influencing it, such as soil texture, structure, salt concentration; and (c) Soil drainage and related properties that influence it like soil texture, structure, depth of water table, nearness to natural drainage ways, etc. These properties have, therefore, been considered in assessing the possible behaviour of the above soils under irrigation and their assessment is as follows :

Soils represented by Profile I : This profile represents soils that are medium textured and non-saline but have high exchangeable sodium percentage in the horizons and hence classified as Natric orthustents. The soil in the surface layers is free from harmful concentrations of salt, and has available moisture capacity of 1.5 to 2 inches per foot of depth which can be looked upon as satisfactory features. However, the high sodium saturation of the subsoil and the very slow permeability indicate severe limitations from the irrigation point of view. These soils would require intensive management measures to keep down the exchangeable sodium content through application of gypsum and also to provide for adequate drainage to prevent water-logging conditions which will effect crop growth. These soils can be classified under land-use capability Class III.

Soils represented by Profile II : This profile represents soils whose surface layers are light textured and are free from harmful concentrations of water-soluble salts or exchangeable sodium and are rapidly permeable. On the other hand, the lower horizons while they have favourable textural conditions have high concentrations of water-soluble salts and also have high amounts of exchangeable sodium. The estimated available water capacity is in the range of $\frac{3}{4}$ to $1\frac{1}{2}$ inches per foot of soil. These limitations combined with the slow permeability of the lower horizons demand that with introduction of irrigation, intensive management measures are taken to provide for good sub-surface drainage, because without this, the water table will rise, and the harmful salts, including sodium, are likely to come up and affect crop growth adversely. These soils can also be placed in capability Class III.

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*Originals not seen.