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Characterization, Classification and Evaluation of Soils of Churu District, Rajasthan

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Soils of Churu were characterized, classified and mapped on 1:50,000 scale. The results showed that the soils of aeolian plains (93.9% area of Churu) were very deep, somewhat excessively drained, loamy sand to fine sand, single grained, moderately alkaline and were mapped as association of normal, moderately and highly hummocky phase of Molasar, Modasar and Dune complex series. Chirai series with its hummocky phase were the other soils of aeolian plains. These were moderately deep, well drained, fine sand to loamy sand, single grained at the surface, loamy sand to sandy loam in the subsurface with fine to medium weak subangular blocky structure on lime-rich substratum. Devas series, occurring as association of shallow and moderately deep phase, had sandy mantle on lime sediment rich in silica nodules. Soils of alluvial plains (6.1% of the district) were sandy loam, occasionally silty loam with medium moderate sub-angular blocky structure and were mapped as association of Masitawali, Saroopdesar and Naurangpura series. An excessive drainage and higher sand content restricted pedological manifestations in soils of aeolian plains, while the distance from the source of alluvia and load of overburden sand governed pedality in soils of alluvial plains. Molasar, Modasar, Devas and Dune complex were classified as Typic Torripsamments, while Naurangpura series as Typic Torrifluvents subgroups of Entisol soil order. Chirai series was classified as Typic Haplocalmbids, while Masitawali and Saroopdesar were placed in Fluventic Haplocambids subgroups of Aridisol soil order. Land suitability evaluation of these soils is described for arid agriculture and other alternate land uses

Key words: Arid soil, characterization, classification, soil suitability evaluation

Churu in Rajasthan is the most desiccated district of Indian arid zone. It experiences low, erratic and spotty rainfall, high temperature with large variations, annals of drought, high wind speed and low biological productivity. Soils vary widely with respect to morphology, lime and silica content. These together with very low irrigation potential constitute a fragile ecosystem that supports traditional systems of existence, cereal cropping and pastoralism. Agricultural intensification and massive infrastructure development in the recent years without considering the variability of entire production system enhances the risk of soil erosion and fertility depletion (Singh *et al.* 2007). High grazing and human interference further accentuates severity of erosion which ultimately reduces biological productivity. Therefore, developing and adopting an ideal land use plan based on the soil quality and constraints is of immense use for achieving the goal of sustainability. Characterization, classification and evaluation of soils for different land uses are the first milestone to develop sustainable and eco-friendly land use models. Present investigation was conducted to characterize and classify the soils of the district and evaluate suitability of these for agricultural and alternate land uses.

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Materials and Methods

Geographic Setting

The district Churu, extending between 27^0 24' to 29^0 00' N latitude and 73^0 40' to 75^0 41'E longitude with an area of 13592 km^2, encompasses vast stretches of sandy flats and undulating sandy plains (dune height of 6 to 50 m) on an altitude of 213 to 400 m above mean sea level. A high aridity index (75 to 83%) and extreme temperature fluctuation (-1.8 to

49.2 °C) separate Churu from other districts of Rajasthan. It is bounded with Mahendragarh and Hissar districts of adjoining Haryana state in the east and is encircled with the districts of Rajasthan from other three sides, namely Hanumangarh in the north, Nagaur, Sikar and Jhunjhunu in south; south east and Bikaner in the west (Fig.1). Aeolian plains are the major landforms, while a trap of alluvial plain was marked along the Kantali river, draining the district. Average annual rainfall is 353.5 mm, increasing from 261.2 mm at Dungargarh to 372.3 mm at Sujangarh with 40 to 50% coefficient of variation. Bulk of rainfall is received during onset of summer monsoon in 17 to 21 rainy days. Relative humidity remains below 52% in most parts of the year. The annual evapotranspiration (on an average 1500-1600 mm) exceeds the precipitation characterizing very short growing period. Pearl millet, *guar*, *moth, moong* and *til* are the important crops. Wheat and mustard are grown with irrigation, while gram is cultivated with the support of conserve moisture and winter rains (*Mawat*). There is a marked shift in land use since the last four decades (1957-58 to 1998-99). The area under cultivable waste, other fallow land and current fallows has declined by 93.8, 67.8 and 43.61%, respectively. The net irrigated area has increased tremendously from 123 ha to 48050 ha during the period (Balak Ram *et al.* 2003).

Field and Laboratory Studies

Soil survey has been carried out on 1:50,000 scale following three tier approach i.*e.* image interpretation (IRS LISS III data); laboratory and field investigation for correcting landform boundary and characterizing soils (Soil Survey Staff 2003); map printing and cartography. During field detailed morphological studies (Soil Survey Division Staff 1995) were carried out and horizon-wise soil samples were collected for detailed laboratory characterization. Besides these, several auger bores were also examined during the course of field traverse for correlating the soils and correcting soil boundary. The analysis of physical and chemical characteristics of soils was carried out following standard analytical procedures (Black 1965; Jackson 1973). Particle size analysis was carried out by international pipette method (Piper

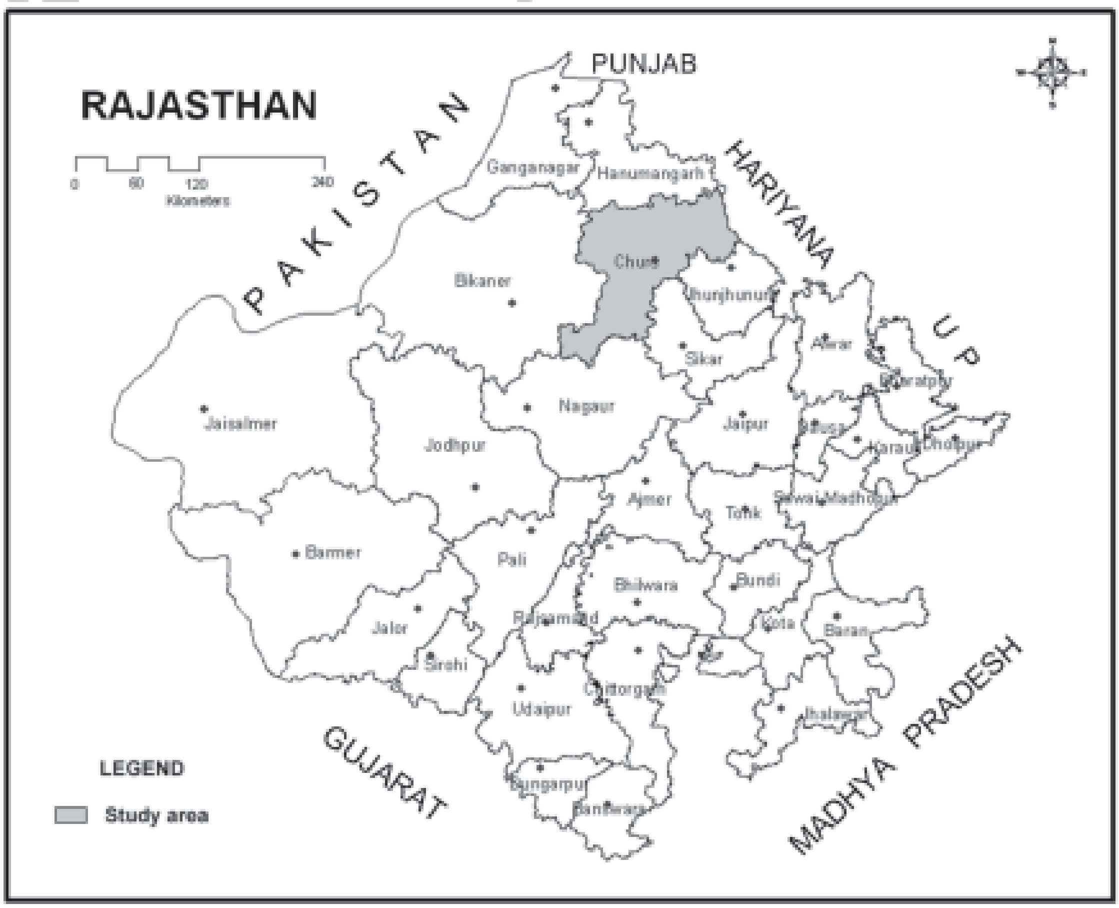

Fig. 1. Location map of the study area

1966) using sodium-hexameta-phosphate as a dispersing agent. The textural class was determined using the USDA textural triangle. The soil reaction (pH of 1:2 soil water suspension) was determined by pH meter (Jackson 1973). Electrical conductivity (EC) of soil extract was determined using conductivity bridge (Richards 1954). Organic carbon and calcium carbonate content in soils were estimated following methods given by Piper (1966). The CEC was determined by saturation of soils with 1*N* sodium acetate (pH 8.2). After removal of excess sodium acetate by washing with ethanol till the supernatant gave an EC of 0.040-0.055 dS m^{-1}, the absorbed sodium was replaced by ammonium acetate (pH 7.0) solution and the sodium concentration in the lechate was determined by flame photometer. Available phosphorus was determined by Olsen method (Olsen *et al.* 1954) and available potassium was estimated by flame photometer after extraction with neutral normal ammonium acetate solution (pH 7.0). Eight soil series and their phases were characterized and mapped (Table 1) in the course of investigation. Five soil series (Chirai, Molasar, Modasar, Devas and Dune complex) belonging to the aeolian plain covering 93.9% area of Churu and three others (Masitawali, Naurangpura and Saroopdesar) were identified (Fig. 2) in alluvial plains (6.1% area of Churu). The soils were classified using USDA System of Soil Classification (Soil Survey Staff 2003). Soil suitability evaluation was carried out following FAO framework (FAO 1976) and as per guidelines described by Sys *et al.* (1991). Land use requirement as given by Sys *et al.* (1991) was modified based on the personal experience and published results of local experiments.

Results and Discussion

Morphological Characteristics

Soils of the district were light yellowish brown (10YR6/4) to pale brown (10YR6/3). Value and chroma ranged from 5 to 6 and 3 to 4 in the surface soils of Masitawali, Saroopdesar, Naurangpura, Chirai and Modasar series; however, subsoil exhibited dominantly one unit darker chroma and value in hue of 10YR. It was primarily attributed to higher silt and clay content *vis-à-vis* higher moisture retention for longer duration (Table 1). However, higher lime content (Ck horizons) in Devas and Chirai series (Table 2) overshadowed the influence of higher silt and clay and induced grayer value and chroma, ranging from 6 to 7 and 1 to 2, respectively in 10YR Hue (Singh *et al.* 1999). An excessive drainage was responsible for dark brown colour (7.5YR) in subsoils of Molasar series. Highly and moderately hummocky phases of Molasar, Modasar, Chirai and Dune complex series showed similar colour characteristics (10YR6/3 to 10YR6/4) at the surface because of common source of aeolian sand. The observation is in conformity with the higher organic carbon content in the subsurface than their surface counterpart, which received fresh overburden sand from the adjoining dunes (Table 2).

Soft powdery lime and lime concretions were characteristic of Chirai series; lime sediments with interspersed silica nodules in Devas series restricted soil depth; otherwise soils were very deep to deep. Lime content also restricted water movement; otherwise internal drainage was read as excessive to well, depending upon topography and clays. Results corroborate the findings of Singh *et al.* (1999).

Fine sand and loamy sand texture was dominantly observed on the surface and in the subsurface, respectively in Molasar, Chirai, Modasar and Devas series. Fine sand characterized the dune complexes, while loamy sand and sandy loam textural classes were noted below the surface in Masitawali and Chirai series (Table 1). Soils of Naurangpura series showed dominantly silty loam textural class at the surface and sandy loam, sometimes loam in the sub-surface. Structurally soils were single-grained on the surface and had very fine to fine, weak sub-angular blocky structure in the subsurface of Molasar, Devas and Modasar series. Medium moderate sub-angular blocky structure was noticed below the surface in Masitawali and Saroopdesar series. Structure development ran parallel to the clay content and textural class. However, precipitation of lime in pores discounted the influence of clays and accounted for massive soil structure below the solum in Devas and Chirai series. Mark of stratification and sign of sedimentation were the characteristic features of Naurangpura series.

Soil textural class and clay content also accounted for consistence in soils of Churu. Dry, moist and wet consistence was examined as loose, loose and none sticky and none plastic, respectively in Dune complex, Molasar, Modasar and in first 30 cm soils of Chirai, Devas, Saroopdesar and Masitawali series. Coherence of soil particles increased down the depth in Chirai, Devas, Saroopdesar and Masitawali series and consistence was read as soft, very friable, slightly sticky and none-plastic (Table 1). However, lime and silica content slightly modified the moist and wet consistence in Chirai and Devas series, which were examined friable as moist; slightly sticky and slightly plastic as wet consistence.

Table 1. Morphological characteristics of soil series of Churu district

Horizon	Depth (cm)	Colour	Texture*	Structure**	Consistence# dry	moist	wet	Boundary##
Molasar series: Typic Torripsamments								
AP	0-15	10YR5/4	fs	sg	l	l	s0/p0	
C1	15-45	10YR5/4	fs	sg	l	l	s0/p0	cs
C2	45-90	7.5YR5/4	ls	sg	l	l	s0/p0	ds
C3	90-130	7.5YR4/4	ls	sg	l	l	s0/p0	ds
Chirai series: Typic Haplocambids								
AP	0-12	10YR6/3	fs	sg	l	l	s0/p0	
A2	12-42	10YR5/4	ls	sg	l	l	s0/p0	cs
Bw1	42-75	10YR6/3	ls	f 1 sbk	h	vfr	ss/p0	gs
Bw2	75-90	10YR5/3	ls	m 1 sbk	h	vfr	ss/p0	gs
Ck1	90-130	10YR6/3	fsl	massive	h	vfr	ss/p0	aw
Ck2	130-170	10YR6/3	gsl	massive	h	vfr	ss/p0	gs
Modasar series: Typic Torripsamments								
AP	0-20	10YR6/4	fs	sg	l	l	s0/p0	
C1	20-60	10YR5/4	fs	sg	l	l	s0/p0	cs
C2	60-120	10YR5/4	ls	sg	l	l	s0/p0	ds
C3	120-160	10YR6/4	ls	sg	l	l	s0/p0	ds
Devas series: Typic Torripsamments								
AP	0-15	10YR6/4	ls	sg	l	l	s0/p0	
A1	15-35	10YR5/2	ls	sg	l	l	s0/p0	cs
Ck1	35-50	10YR5/2	ls	massive	h	fr	ss/p0	aw
Ck2	50-75	10YR6/1	gsl	massive	h	fr	ss/p0	gs
Masitawali series: Fluventic Haplocambids								
AP	0-15	10YR6/4	ls	f 1 sbk	sh	vfr	s0/p0	
A2	15-45	10YR5/3	sl	f 2 sbk	sh	fr	ss/p0	cs
Bw	45-75	10YR5/4	sl	f 2 sbk	sh	fr	ss/p0	gs
C1	75-120	10YR5/4	l	m 2 sbk	sh	fr	ss/ps	gs
C2	120-150	10YR4/4	l	m 2 sbk	sh	fr	ss/ps	gs
Saroopdesar series: Fluventic Haplocambids								
AP	0-30	10YR6/4	ls	sg	sh	fr	s0/p0	
A2	30-60	10YR4/3	sl	m 2 sbk	sh	fr	ss/p0	cs
Bw1	60-90	10YR4/3	sl	m 2 sbk	sh	fr	ss/p0	gs
Bw2	90-130	10YR3/3	l	m 2 sbk	sh	fr	ss/p0	gs
C1	130-160	10YR4/3	l	m 1 sbk	sh	fr	ss/p0	gs
Naurangpuraa series: Typic Torrifluvents								
AP	0-20	10YR5/3	sil	f 1 sbk	sh	fr	s0/p0	
C1	20-40	10YR3/3	sil	f 1 sbk	sh	fr	s0/p0	cs
C2	40-65	10YR3/3	sl	f 1 sbk	sh	fr	s0/p0	cs
C3	65-105	10YR5/3	l	f 1 sbk	sh	fr	s0/p0	as
C4	105-150	10YR5/3	ls	f 1 sbk	sh	fr	s0/p0	as
Dune Complex series: Typic Torripsamments								
AP	0-30	10YR6/3	fs	sg	l	l	s0/p0	
C1	30-70	10YR6/4	fs	sg	l	l	s0/p0	ds
C2	70-100	10YR6/4	fs	sg	l	l	s0/p0	ds
C3	100-130	10YR6/4	fs	sg	l	l	s0/p0	ds
C4	130-180	10YR6/4	fs	sg	l	l	s0/p0	ds

*ls-loamy sand; fs-fine sand; sil-silt loam; l-loam; sl-sandy loam; fsl-fine sandy loam; gsl-gravelly sandy loam
**sg-single grained; f-fine, m-medium, 1-weak, 2-moderate, sbk-subangular blocky;
l-loose, sh-slightly hard, fr-friable; vfr-very friable; ps-slightly plastic; s0-none sticky; ss-slightly sticky, p0-none plastic
cs-clear smooth, ds-diffuse smooth, as –abrupt smooth, gs-gradual smooth, aw –abrupt wavy.

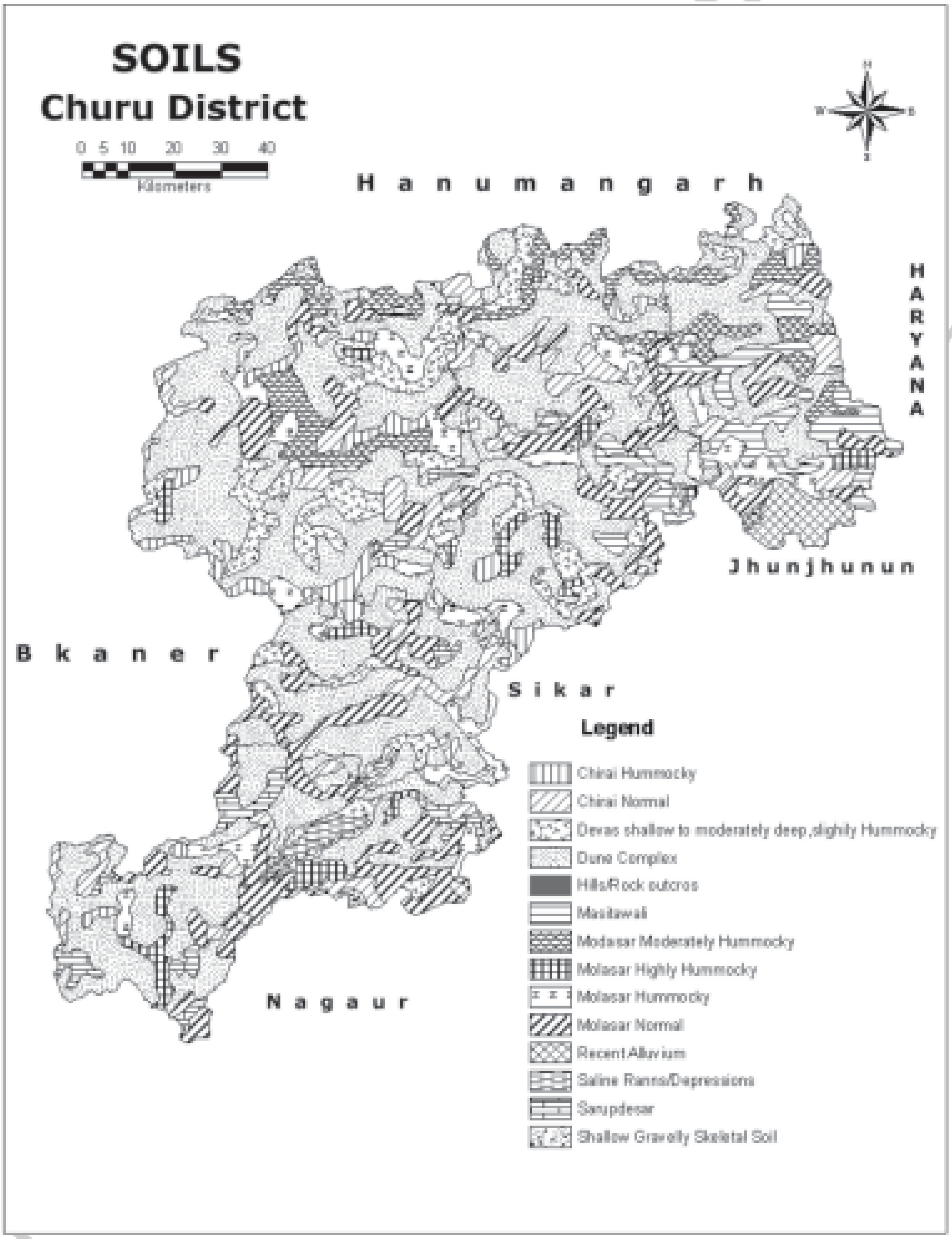

Fig.2. Dominant soil series of Churu District

The A-C horizon sequence characterized Dune complex, Molasar, Modasar and Naurangpura series, while Ap-Bw horizon sequence defined Masitawali and Saroopdesar series. Chirai series showed a horizon sequence of Ap-Bw-Ck, while Devas series had a horizon sequence of A-Ck. Boundary between the two adjacent horizons was either clear smooth or gradual smooth/ diffuse smooth, except abrupt and wavy boundary between Bw and Ck; A and Ck horizons of Chirai and Devas series, respectively.

Physical and Chemical Characteristics

Soils of Dune complex contained 85 to 96% sand, of which 81 to 91% was fine sand (Table 2). Clay and silt content varied from 2.6 to 5.1 and 1.5 to 2.8%, respectively. Water holding capacity (18 to 25%), organic carbon content (0.4 to 1.2 g kg^{-1}), available phosphorus (1.8 to 9.0 kg ha^{-1}) and potassium (65 to 157 kg ha^{-1}) were very low to low, occasionally medium (Muhr *et al.* 1963). Available micronutrients (Fe, Mn and Cu) were adequate except occasional deficiency of zinc at places.

Table 2. Physical and chemical characteristics of soils

Depth (cm)	Sand	Silt	Clay	WHC	CaCO$_3$	Org.C	pH (1:2)	EC (dS m^{-1})	CEC [cmol(p$^+$)kg^{-1}]	P	K
	%				g kg^{-1}					kg ha^{-1}	
Molasar series: Typic Torripsamments											
0-15	91.0	4.2	4.8	24.4	0.0	1.0	8.1	0.11	2.9	13	297
15-45	86.0	8.3	5.7	28.8	0.0	1.2	8.2	0.12	3.8	9.2	191
45-90	84.7	7.5	7.8	30.7	0.0	1.0	8.1	0.10	4.9	5.7	161
90-130	84.1	7.1	8.8	32.6	0.0	1.4	8.1	0.05	4.8	3.7	113
Chirai series: Typic Haplocambids											
0-12	88.5	4.5	7.0	24.6	15.0	0.9	8.4	0.14	3.0	12.6	269
12-42	84.8	5.5	9.7	27.3	59.5	1.2	8.5	0.10	4.8	7.7	169
42-75	83.8	5.9	10.3	29.0	82.0	1.5	8.5	0.11	5.1	9.2	150
75-90	84.8	5.8	9.4	30.0	94.5	1.2	8.5	0.08	5.4	5.7	150
90-130	84.5	6.2	9.3	29.6	114.0	1.5	8.4	0.05	5.6	3.2	162
130-170	80.2	10.2	9.6	29.6	128.5	1.8	8.4	0.05	5.8	3.2	150
Modasar series: Typic Torripsamments											
0-20	91.6	3.4	5.0	21.8	5.5	0.9	8.3	0.09	1.9	10.1	191
20-60	87.8	5.0	7.2	26.2	15.0	1.0	8.4	0.15	3.5	7.7	186
60-120	85.7	6.0	8.3	28.0	38.0	1.0	8.4	0.25	4.6	4.1	113
120-160	86.8	6.2	7.0	26.7	44.0	0.8	8.4	0.25	4.6	4.1	101
Devas series: Typic Torripsamments											
0-15	89.5	4.5	6.0	23.00	23.0	1.2	8.3	0.21	2.4	11.1	180
15-35	84.3	8.5	7.2	26.80	58.0	1.2	8.5	0.21	2.8	7.4	135
35-50	81.2	9.8	9.0	28.00	87.0	1.6	8.4	0.10	4.8	7.4	113
50-75	79.5	8.7	11.8	32.00	118.0	0.8	8.4	0.08	6.2	5.6	113
Masitawali series: Fluventic Haplocambids											
0-15	86.2	7.6	6.2	23.0	0.0	2.1	8.0	0.15	6.2	23.0	420
15-45	73.5	13.8	12.7	30.8	0.0	1.7	8.3	0.18	7.9	18.7	308
45-75	66.2	18.0	15.8	36.0	18.0	1.2	8.2	0.17	9.2	14.3	275
75-120	64.5	20.5	15.0	36.8	40.0	2.1	8.2	0.21	10.3	11.7	275
120-150	59.3	21.0	19.7	37.8	80.0	2.4	8.1	0.27	12.2	9.3	190
Saroopdesar series: Fluventic Haplocambids											
0-30	85.2	5.8	9.0	26.0	0.0	1.9	8.3	0.10	5.8	25.0	378
30-60	72.1	13.0	14.9	29.0	0.0	1.5	8.2	0.13	6.7	21.7	402
60-90	69.0	15.0	16.0	32.9	0.0	1.5	8.3	0.15	9.2	18.7	338
90-130	63.2	16.0	20.8	36.3	0.0	2.5	8.2	0.20	9.8	14.3	208
130-160	60.2	21.8	18.0	38.2	0.0	2.5	8.2	0.15	11.5	11.7	160
Naurangpura series: Typic Torrifluvents											
0-20	50	30.3	19.7	49.8	90.0	3.5	8.5	0.65	20.8	27.0	478
20-40	48.7	35.0	16.3	48.4	70.0	2.5	8.4	0.61	21.5	23.7	281
40-65	75.7	11.7	12.6	32.0	11.0	1.8	8.6	0.54	8.8	13.4	2.03
65-105	62.7	18.3	19.0	38.8	4.0	2.5	8.4	0.46	12.7	11.7	258
105-150	86.4	5.8	7.8	28.0	3.0	1.2	8.2	0.61	5.3	9.5	169
Dune Complex series: Typic Torripsamments											
0-30	94.6	1.3	4.1	24.4	0.0	0.8	8.3	0.00	1.7	6.2	130
30-70	94.0	1.9	4.2	24.6	0.0	0.5	8.2	0.04	2.0	5.0	98
70-100	93.7	2.1	4.2	25.2	1.0	0.8	8.2	0.08	2.2	3.2	75
100-130	93.4	2.0	4.6	25.9	2.0	1.2	8.4	0.12	2.6	1.7	69
130-180	92.7	2.2	5.1	26.2	2.0	1.2	8.3	0.10	2.6	1.7	68

Molasar and Chirai series contained relatively higher clay (4.0 to 11.0%) and silt (2.5 to 8.5%) than the dominant dune complex series. Fine sand (72 to 85%) and water holding capacity (23 to 35%) moved parallel to that of silt and clay. These soils were moderately alkaline (7.9-8.5), having 2.8 to 6.0 cmol(p$^+$)kg^{-1} cation exchange capacity; very low organic carbon (0.5-2.5 g kg^{-1}), low to medium available phosphorus (3.0 to 15.0 kg ha^{-1}) and medium to high potassium (135 to 350 kg ha^{-1}). These were well supplied with respect to available micronutrients. Mean organic carbon (1.1, 0.5 to 2.2 g kg^{-1}), available phosphorus (3.5 to 14 kg ha^{-1}) and potassium (96 to 305 kg ha^{-1}) in Modasar series resembled to that of

Molasar and Chirai series (Table 2). These results are in agreement with the findings of Dhir (1977), Ahuja *et al.* (1992, 1996) and Sharma *et al.* (2006).

Masitawali and Saroopdesar series were moderately alkaline and non-calcareous in the control section, while other series Naurangpura in alluvial plains was calcareous. Water holding capacity in Masitawali ranged from 28 to 37%; cation exchange capacity varied from 5.7 and 11.5 cmol$(p^+)kg^{-1}$. Organic carbon (0.9-3.5 g kg^{-1}) was low; available phosphorus (10 to 23.0 kg ha^{-1}) was medium while potassium availability was marked as medium to high (170-450 kg ha^{-1}). Clay and silt content ranged from 5.8 to 36 and 7.8 to 20.8%, respectively in soil profiles of Naurangpura and Saroopdesar series. These have comparatively higher water holding capacity (28-47%), cation exchange capacity [8 to 20 cmol$(p^+)kg^{-1}$], organic carbon, available phosphorus, available potassium and DTPA extractable micronutrients than the other soils of the district (Dhir and Kolarkar 1977; Sharma *et al.* 1985; Gupta *et al.* 2000).

Pedogenesis

An excessive drainage and a high sand content (>90%) in Dune complex; comparable in Molasar, Devas, Modasar and in first 0-30 cm soils of Chirai series (80 to 90%) restricted pedogenesis. However, comparatively higher fine sand *vis-a-vis* higher water holding capacity in subsoils of Chirai series than other soils of aeolian plain had led to the development of Bw horizon (Cambic horizons) in terms of structural improvement (fine to medium, weak subangular blocky structure) and signature of lime movement. Lime content of 8 to 12% in Ck horizons of Chirai and Devas precluded the pedogenic process to move forward because of plasma immobilization (Rimmer and Greenland 1976; Boul *et al.* 1980) and massive soil structure was noted in the respective horizons. Carbonates played a similar role in Ck horizon of Naurangpura series of alluvial plains. Since Masitawali and Saroopdesar series were situated away from the source of alluvium and had fairly high silt clay content (13 to 22%) exhibited high degree of pedality in terms of medium moderate sub-angular blocky structure and medium common porosity. Irregular distribution of organic carbon (Table 2) indicated that pedogenesis was not strong enough to obliterate the mark of stratification. The pedality was marked weak in soils of Nauragpura series, which was located near the source of alluvia, receiving fresh sediments during rains. This may be the probable reason that restricted the pedogenesis in Naurangpura series. A sharp decline of silt and clay content after first 50 cm of the soil profile further endorsed the findings. An irregular distribution of organic carbon (Table 2) confirms the factuality of the observation as well.

Classification of Soils

Lime accumulation, mark of stratification, organic carbon distribution, silt and clays and structural development were marked as the diagnostic characteristics for classifying the soils of Churu. Based on these Dune complexes, Molasar, Modasar, Devas and Naurangpura series were classified in Entiosls, while Chirai, Saroopdesar and Masitawali series were placed in Aridisols. Sand content of more than 80% throughout the soil profile was the criteria to place soils of Molasar, Modasar, Devas and Dune complex as Psamments, while irregular distribution of organic carbon and mark of stratification was chosen as criteria for grouping Naurangpura series as Fluvents. Cambic horizon was the basis for classifying Chirai, Masitawali and Saroopdesar series as Cambids. Accounting aridic soil moisture regime as the differentiae characteristics at great group level, Psamments and Fluvents were classified as Torripsamments and Torrifluvents, respectively. Cambids were taken down to Haplocambids. Torripsamments, Haplocambids and Torrifluvents represented the central concept of great group, consequently classified as Typic Torripsamments, Typic Haplocambids and Typic Torrifluvents at the subgroup level. Other Haplocambids were classified as Fluventic Haplocambids accounting for fluvial action in the alluvial plains. Typic Torrifluvents (Naurangpura series); Fluventic Haplocambids (Masitawali/ Saroopdesar series) and Typic Haplocambids (Chirai series) were classified as the member of coarse loamy, mixed hyperthermic family of their respective subgroups at family level. Classification of Typic Torripsamments is not allowed below the subgroup level.

Distribution of Soils

Dune complex series covered 6686.60 km^2, comprising 49.2% of the total geographical area of Churu district. Molasar, Modasar, Devas and Chirai with their respective phases in aeolian plains were mapped on 2986.5, 725.6, 971.3 and 1221.4 km^2 area, occupying 22.0, 7.1, 7.1 and 8.2% area of the district, respectively. Area under Masitawali, Saroopdesar and Nauragpura was 506.1, 297.8, 196.8 km^2, covering 2.7, 2.2 and 1.5% area of Churu. Soil series of aeolian plain together was mapped on 93.9%

Table 3. Land suitability evaluation for various land uses in the district

Soil series	Crop cultivation		Horticulture	Agroforestry	Forestry	Silvipasture	Pasture
	Rainfed	Irrigated					
Dune complex	N	N	N	S3	S1	S1	S1
Molasar	S2	S2	S1	S1	S3	S3	S3
Molasar hummocky	S3	S3	S3	S3	S1	S1	S1
Chirai	S2	S2	S1	S1	S3	S3	S3
Chirai hummocky	S3	S3	S3	S3	S1	S1	S1
Modasar	S2	S2	S1	S1	S3	S3	S3
Devas	S2	N	S2	S2	S2	S2	S1
Masitawali	S1	S1	S1	S1	S3	S3	S3
Saroopdesar	S1	S1	S1	S1	S3	S3	S3
Naurangpuraa	S1	S1	S1	S1	S3	S3	S3

S1; Highly suitable, S2; Moderately suitable, S3; Marginally suitable, N; Not suitable

area of Churu, while soil series Alluvial Plain was registered on 6.1% area of the district including a small part of the area classified as gravelly shallow skeletal soils (Tables 1 and 2; Fig. 2).

Soil Suitability Evaluation

Parts of Molasar, Modasar, Chirai and Devas series occurring on interdunal flats were moderately suitable (S2) for growing pearl millet, cluster bean, *moong* and moth bean with safety measures to protect the land from erosion, while hummocky phase of these soils were marginally/ not suitable (S3/N3) for cropping because of excessive risk of erosion. The Dune complex and highly hummocky part of Molasar series were not suitable (N) for any type of cropping and tillage operation. Masitawali, Saroopdesar and Naurangpura series were highly suitable (S1) for rainfed cultivation. Under irrigated agriculture, Saroopdesar and Masitawali series were highly suitable (S1) for growing of wheat, mustard, barley and gram. However, soils of Naurangpura may be used with precaution under irrigated condition because of high lime content in the subsurface. Soils of Molasar, Modasar and Chirai series were moderately suitable (S2) for wheat, barley, gram and mustard with improved method of irrigation such as sprinklers. Hummocky part of these soils was marginally suitable for agriculture under pressurized irrigation because of undulated relief.

Soils of Molasar, Modasar and Chirai series are highly suitable (S1) for agroforestry. *Prosopis cineraria*, *Tecomella undulata*, *Acacia senegal*, *Acacia albida* and *Albizia* tree species in combination with pearl millet, *moong*, moth bean and cluster bean may be successfully grown. Hummocky parts of these soils may be kept for growing grasses. Besides these, lands can also be used for horticultural plantation. Molasar, Modasar and Chirai series were highly suitable (S1) for growing *ber*, *karonda* and *kair* and hummocky parts of these soils were moderately suitable for these crops. Dune complex on account of undulating relief and droughtiness were neither suitable for horticultural plantation (Vashishtha and Prasad 1997) nor for agroforestry. Dune complex and highly hummocky part of Molasar were highly suitable for silvipasture and pasture.

Conclusion

Wind erosion is the major constraint for sustainable agriculture in Churu district. Aeolian sand not only affects dunes and inter-dunes of the district but also gallops good agricultural land of alluvial plains. At the places aeolian activity is prominent enough to restrain the process of alluviation in alluvial plains. Sand content and associated properties were the dominant diagnostic characteristics for soil classification. Therefore keeping sand at the place should be the main focus for attaining the sustainability and the soil-based agri-silvipostoral model may be ideal for this purpose.

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