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Characterization and classification of soils using morphological and physicochemical properties in major barley-growing areas of Rajasthan

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Abstract

The present study, entitled “Characterization and Classification of Soils Using Morphological and Physicochemical Properties in Major Barley-Growing Areas of Rajasthan,” was carried out to evaluate the soil characteristics and suitability of major barley-growing regions of Rajasthan. Representative soil profiles were studied from the districts of Sri Ganganagar, Udaipur, and Sikar, representing diverse agro-climatic conditions. Considerable variability was observed in the morphological, physical, and physicochemical properties of the soils across the study areas. The soils of Sri Ganganagar and Sikar were predominantly coarse-textured, varying from sand to loamy sand, whereas the soils of Udaipur ranged from sandy clay loam to clay loam. Bulk density varied between 1.18 and 1.71 Mg m⁻³, porosity ranged from 34.75 to 54.86%, and water holding capacity varied from 24.67 to 51.00%. Soil reaction ranged from neutral to moderately alkaline, with pH values between 7.16 and 8.90, while electrical conductivity remained within the safe range for barley cultivation. Organic carbon content was generally low in Sri Ganganagar and Sikar soils (0.06–0.22%) but comparatively higher in Udaipur soils (0.28–0.60%). Exchangeable cations followed the order Ca²⁺ > Mg²⁺ > Na⁺ > K⁺, and cation exchange capacity ranged from 13.60 to 43.20 cmol(p⁺) kg⁻¹. Available nitrogen, phosphorus, and potassium contents ranged from 101.34–315.25, 12.02–24.40, and 132.59–233.84 kg ha⁻¹, respectively. Based on the observed morphological and physicochemical characteristics, the soils were classified as Typic Haplocambids, Typic Haplocalcids, and Vertic Haplustepts. The findings indicated that the soils of Udaipur were comparatively more suitable for barley cultivation due to their better fertility status and higher water retention capacity than those of Sri Ganganagar and Sikar.

Keywords: Soil characterization, morphological properties, physicochemical properties, soil classification, land suitability and soil fertility, Rajasthan

Introduction

Barley (*Hordeum vulgare* L. is a very old cultivated cereal which comes in fourth in global production behind maize, wheat and rice (Pal *et al.*, 2012) [19]. It is a popular choice for food, feed and malting grain due to its nutrition and industrial value (Baik and Ullrich, 2008) [4]. Also it is a good source of dietary fiber which in particular is of beta glucan that which gives it health and nutraceutical benefits (Newman and Newman, 2006) [17]. In India barley is mainly grown in marginal and resource poor areas which includes Rajasthan, Uttar Pradesh, and Haryana. In 2022-23 barley covered about 0.62 million hectares which produced a total of 1.84 million tonnes (Anonymous, 2023).

Rajasthan is one of the major barley-growing states of India; however, variability in soil properties across different agro-climatic regions significantly influences crop productivity and quality. Soil characterization provides information on important properties such as soil colour, texture, structure, consistency, drainage, and horizon development, which help in understanding soil potential and identifying production constraints. Physicochemical properties including soil reaction, electrical conductivity, organic carbon, cation exchange capacity, and nutrient status also play a vital role in determining soil fertility and suitability for barley cultivation.

Soil classification is important for grouping soils based on their physical, chemical, and mineralogical characteristics and for developing suitable management practices for sustainable crop production (Sharu *et al.*, 2013) [24]. In addition, land capability and irrigability classifications help in assessing the sustainable agricultural use of soils under different management conditions (Palaskar *et al.*, 1987) [20]. Therefore, the present investigation was undertaken to characterize

and classify the soils of major barley-growing areas of Rajasthan based on their morphological, physical, and physicochemical properties.

Materials and methods

The present investigation was conducted in major barley-growing regions of Rajasthan to evaluate the morphological, physical, and physicochemical characteristics of soils and their suitability for barley cultivation. Nine representative soil profiles were selected from barley-growing areas of Udaipur, Sikar, and Sri Ganganagar districts representing different agro-climatic conditions. Field investigations were carried out to study soil genesis and pedogenic processes, including observations on horizon differentiation, soil colour, texture, structure, consistency, drainage, slope, cracks, and carbonate accumulation following the USDA Soil Survey Manual (1995), Handbook No. 18. Soil profile pits (2 × 1.5 m) were excavated up to the regolith layer or 150 cm depth. Soil samples from each horizon were collected, air-dried, processed through a 2 mm sieve for laboratory analysis, and undisturbed soil clods were collected separately for bulk density determination.

Among the studied profiles, the Sri Ganganagar soil profiles GN/P-1 (29.87264° N, 73.91321° E), GN/P-2 (29.80152° N, 73.76794° E), and GN/P-3 (29.4913° N, 73.3934° E) were located under hot arid climatic conditions and developed from aeolian modified alluvial plains and alluvial parent materials. The soils varied from level to undulating slopes (0–8%) with excessive to well drainage, slow to very slow runoff, and moderate to severe erosion. According to USDA Soil Taxonomy, these soils were classified as coarse-loamy to fine-loamy, mixed carbonates/calcareous, hyperthermic Typic Haplustepts. Similarly, the Udaipur soil profiles UDR/P-4 (24.653° N, 74.015° E), UDR/P-5 (24.658° N, 74.008° E), and UDR/P-6 (24.667° N, 74.020° E) were located under hot semi-arid to hot dry semiarid climatic conditions and developed from metamorphosed rocks such as phyllite, schist, quartzite, granite, gneiss, limestone, and marble. These soils occurred on nearly level to gently sloping lands (0–5%) with moderately well drainage, slight erosion, and medium runoff, and were classified as coarseloamy to fine-loamy, mixed, non-calcareous, hyperthermic Typic Haplustepts. In contrast, the Sikar soil profiles SKR/P-7 (27.6094° N, 75.1399° E), SKR/P-8 (27.9944° N, 74.9563° E), and SKR/P-9 (27.8225° N, 75.0270° E) were developed from aeofluvial plains under hot semi-arid climatic conditions. The soils occurred on level to undulating topography (0–8%) with excessive drainage, rapid runoff, and severe erosion. According to USDA Soil Taxonomy, these soils were classified as coarseloamy, mixed, non-calcareous, hyperthermic Typic Ustipsamments.

The collected soil samples were analysed for various physical and physicochemical properties using standard laboratory procedures. Mechanical composition was determined by the International Pipette Method (Piper, 1950)^[22]. Bulk density and particle density were determined by the undisturbed core sampler method (Blake and Hartge, 1986)^[5] and relative density bottle method (Richards, 1954)^[23], respectively. Soil porosity was calculated from bulk density and particle density values, while water holding capacity was determined by the gravimetric method (Vehmeier and Hendrickson, 1931)^[31]. Soil reaction (pH) and electrical conductivity (EC) were measured in a 1:2 soil-water suspension following standard procedures (Richards, 1954)^[23]. Organic carbon content was estimated by the Walkley and Black rapid titration method (Walkley and Black, 1934)^[32], whereas cation exchange

capacity (CEC) was determined using neutral normal ammonium acetate (Metson, 1956)^[16]. Calcium carbonate content was estimated by the acid neutralization method (Allison and Modi, 1965)^[1]. Exchangeable sodium and potassium were determined using ammonium acetate extraction, while exchangeable calcium and magnesium were estimated using KCl-triethanolamine buffer extraction followed by EDTA titration (Jackson, 1967)^[9]. Available nitrogen, phosphorus, and potassium were estimated by the alkaline permanganate method (Subbiah and Asija, 1956)^[27], Olsen's method (Olsen *et al.*, 1954)^[18], and neutral normal ammonium acetate extraction followed by flame photometric determination (Merwin and Peech, 1951)^[15], respectively. DTPA-extractable micronutrients (Fe, Mn, Zn, and Cu) were determined using an atomic absorption spectrophotometer (Lindsay and Norvell, 1978)^[12].

Further, the studied soil characteristics served as the basis for land capability, irrigability, and suitability classification of the soils. Land Capability Classification (LCC) grouped soils into Classes I to VIII based on limitations such as slope, erosion, drainage, wetness, and soil depth, where Classes I and II were considered most suitable for cultivation, while Classes V to VIII were generally unsuitable for regular cropping. Land Irrigability Classification categorized soils from S1 (highly suitable) to N2 (not suitable) according to slope, erosion hazard, and drainage conditions affecting irrigation potential. Similarly, land suitability classification assessed soils as S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), N1 (currently unsuitable but improvable), and N2 (permanently unsuitable)

depending on the severity of soil and land limitations. Overall, land suitability and irrigability decreased with increasing slope, erosion risk, drainage problems, and other soil constraints.

Results and Discussion

Morphological Properties of Soils

The soils of Sri Ganganagar, Udaipur, and Sikar districts exhibited marked variation in morphological and physical characteristics due to differences in physiography and pedogenic processes. Sri Ganganagar and Sikar soils were predominantly coarse-textured, consisting of sand to loamy sand, with weak horizon development, weak to moderate blocky structure, and calcium carbonate accumulation in subsurface horizons. Soil colours ranged from light brownish grey to pale brown, with increasing effervescence at depth indicating their calcareous nature. In contrast, Udaipur soils showed comparatively better profile development with distinct Ap, Bw, and Bt horizons, darker surface colours, moderate sub-angular blocky structure, and evidence of clay illuviation.

Mechanical analysis revealed the dominance of sand in Sri Ganganagar (67.48–89.81%) and Sikar (75.10–90.20%) soils, whereas Udaipur soils contained relatively higher silt (9.43–26.36%) and clay (6.57–58.50%) contents. Clay content ranged from 1.42–11.04% in Sri Ganganagar and 3.20–13.30% in Sikar soils. The predominance of sand in Sri Ganganagar and Sikar soils reflects the influence of aeolian deposits under arid conditions, while the finer texture of Udaipur soils contributes to greater water-holding capacity and nutrient retention. Overall, the coarse texture, weak horizon differentiation, and calcium carbonate accumulation in Sri Ganganagar and Sikar soils are characteristic of arid-region pedogenesis, whereas the better-developed and finer-textured Udaipur soils reflect the influence of relatively higher rainfall and organic matter content (Meena *et al.*, 2012; Singh and Rathore, 2015; Singh and Rathore, 2017; Kumar *et al.*, 2022; Arya *et al.*, 2025)^[14, 25, 26, 10].

Table 1: Morphological and Physico-Chemical Characteristics of Soil Pedons from Sri Ganganagar, Udaipur, and Sikar Districts

Horizon	Depth (cm)	Colour	Texture	Structure	Consistence	Roots and Pores	Effervescence	Soil Reaction
Sri Ganganagar (GN/P-1)								
Ap	0-20	10 YR 6/2 D to 10 YR 4/2 (M)	Sand Sand %-89.10 Silt %-9.48 Clay %-1.42	medium structure less single grain	loose non-sticky and non-plastic	medium to coarse	strong effervescence	8.6
Bw1	20-38	10 YR 6/2 (D) 4/2 (M)	Loamy sand Sand %- 85.80 Silt%- 10.48 Clay%- 3.72	medium weak single grain	loose non-sticky and non-plastic	medium to coarse	strong effervescence	8.7
Bw2	38-75	10 YR 4/3 (M)	Loamy sand Sand % - 84.40 Silt% - 11.27 Clay % - 4.33	medium weak sub angular blocky	very friable non-sticky and non-plastic	fine coarse	strong effervescence	8.5
Bw3	75-106	10 YR 4/3 (M)	Loamy sand Sand % - 88.48 Silt% - 8.47 Clay % - 3.05	medium moderate sub angular blocky	friable slightly sticky and slightly plastic	fine coarse	strong effervescence	8.4
Bw4	106-150	10 YR 4/3 (M)	Sandy loam Sand % - 89.81 Silt% - 6.41 Clay % - 3.78	medium moderate sub-angular blocky	friable slightly sticky and slightly plastic	fine medium	strong effervescence	8.5
Sri Ganganagar (GN/P-2)								
Ap	0-19	10YR 6/3 (D) 5/3 (M)	Sandy loam Sand % - 79.84 Silt% - 12.48 Clay % - 7.68	medium moderate sub angular blocky	friable	medium coarse pores and few common roots	violent effervescence	8.9
Bw1	19-43	10 YR 6/3 (D) 5/3 (M)	Sandy loam Sand % - 78.84 Silt% - 13.42 Clay % - 8.46	medium weak sub angular blocky	friable	medium coarse pores and very few common roots	violent effervescence	8.8
Bw2	43-82	10 YR 5/3 (M)	Sandy loam Sand % - 77.12 Silt% - 14.21 Clay % - 8.67	medium weak sub angular blocky	friable	fine coarse pores and few common roots	violent effervescence	8.7
Bw2	82-112	10 YR 5/4 (M)	Sandy loam Sand % - 79.84 Silt% - 18.48 Clay % - 1.68	medium moderate sub angular blocky	friable	fine common roots	violent effervescence	8.7
Bw3	112-147	10 YR 5/4 (M)	Sandy loam Sand % - 81.20 Silt% - 14.57 Clay % - 4.23	medium moderate sub angular blocky	friable	fine many	violent effervescence	8.6
Bk	147-160	10 YR 5/3 (M)	Loamy sand Sand % - 83.48 Silt% - 10.47 Clay % - 6.05	medium strong sub angular blocky	firm	very fine many roots	violent effervescence	8.4
Sri Ganganagar (GN/P-3)								
Ap	0-20	10 YR 4/3 (M)	Sandy loam Sand % - 67.48 Silt% - 21.48 Clay % - 11.04	medium weak sub angular blocky	soft friable slightly sticky slightly plastic	fine coarse pores and fine common roots	violent effervescence	8.5
Bw1	20-50	10 YR 6/3 (M)	Sandy loam Sand % - 79.31 Silt% - 18.48 Clay % - 2.21	medium weak sub angular blocky	friable slightly sticky slightly plastic	very fine coarse pores and fine many roots	violent effervescence	8.4
Bw2	50-90	10 YR 6/3 (M)	Sandy loam Sand % - 81.24 Silt% - 16.49 Clay % - 2.27	medium weak sub angular blocky	friable non-sticky non-plastic	medium coarse pores and very fine many roots	violent effervescence	8.3
Bw3	90-125	10 YR 5/4 (M)	Loamy sand Sand % - 84.59 Silt% - 13.58 Clay % - 1.83	medium weak sub angular blocky	friable non-sticky non-plastic	medium coarse pores and very fine common roots	violent effervescence	8.2
Bw4	125-153	10 YR 5/3 (M)	Sand Sand % - 87.97 Silt% - 10.48 Clay % - 1.55	medium weak sub angular blocky	friable non-sticky non-plastic	medium coarse	violent effervescence	8.3
Bk	153-165	10 YR 4/3 (M)	Sand Sand % - 88.69 Silt% - 8.48	medium moderate sub angular blocky	friable sticky plastic	medium coarse	violent effervescence	8.1

			Clay %- 2.83					
Udaipur P-4 (UDR/P-4)								
A1	0-25	10 YR 3/4M	sandy loam Sand % - 67.6 Silt% - 16 Clay %- 16.4	moderate medium, sub angular blocky	slightly hard, friable, slightly sticky	medium pores		7.25
Bw1	25-50	7.5 YR 3/4M	sandy clay loam Sand % - 57 Silt% - 20 Clay %- 23	weak, medium, sub angular blocky	slightly hard, friable, slightly sticky	many medium pores and common roots		7.16
Bw2	50-85	7.5 YR 3/4M	Sandy clay loam Sand % - 55.1 Silt% - 23.9 Clay %- 21	weak, medium, sub angular blocky and distinct mottles	slightly hard, friable, slightly sticky	many medium pores and common roots		7.39
Bw3	85-110	7.5 YR 3/4M	Sandy loam Sand % - 56 Silt% - 25.4 Clay %- 18.6	weak, medium, sub angular blocky	slightly hard, friable, slightly sticky	medium many pores and common roots		7.21
Cr	110+	Weathered material	Sandy clay loam Sand % - 55.2 Silt% - 22.71 Clay %- 22.09					
Pedon 5- Udaipur P-5 (UDR/P-5)								
Ap	0-21	10 YR 3/3M	Clay Sand % - 22.7 Silt% - 22.9 Clay %- 54.4	moderate medium, sub angular blocky	slightly hard, friable, slightly sticky	many medium pores and common roots		7.61
Bw1	21-48	10 YR 3/3M	clay Sand % - 18.5 Silt% - 22.7 Clay %- 58.5	Weak medium, sub angular blocky	slightly hard, friable, slightly sticky	many medium pores and common roots		7.42
Bw2	48-82	7.5 YR 3/2M	Clay Sand % - 19.2 Silt% - 25.6 Clay %- 55.2	Weak medium, sub angular blocky	slightly hard, friable, slightly sticky or plastic	many fine pores and few roots		7.58
Bw3	82-100	10 YR 3/2 M	clay loam Sand % - 46 Silt% - 16.4 Clay %- 37.6	Weak medium, sub angular blocky	slightly hard, friable, slightly sticky or plastic	fine pores and few roots		7.36
Bw4	100-160	7.5 YR 3/2M	sandy loam Sand % - 50.05 Silt% - 25.78 Clay %- 24.17	Weak medium, sub angular blocky	slightly hard, friable, slightly sticky or plastic			7.54
BC	160+	7.5 YR 3/2M	sand clay loam Sand % - 55.2 Silt% - 23.71 Clay %- 21.09	massive structure	friable, slightly plastic			7.59
Udaipur P-6(UDR/P-6)								
Ap	0-20	10YR 3/4 M	sandy loam, 10-20% coarse fragments Sand % - 56.6 Silt% - 26.36 Clay %- 19.04	moderate, medium, sub angular blocky	slightly hard, friable, slightly sticky,			7.74
Bw1	20-45	7.5 YR 3/4 M	sandy clay loam Sand % - 78.81 Silt% - 9.43 Clay %- 11.76	moderate, medium, sub angular blocky	slightly hard, friable, slightly sticky,	Many medium pores and common roots		7.79
Bw2	45-80	10 YR 3/4 M	sandy loam Sand % - 76.6 Silt% - 16.6 Clay %- 8.1	coarse strong sub angular blocky	slightly hard, friable, slightly sticky and plastic	Many medium pores and few roots		7.76
Bw3	81-110	10 YR 5/4 M	sandy loam Sand % - 74.5 Silt% - 18.5 Clay %- 7	massive sub angular blocky	slightly hard, friable, slightly sticky and non-plastic;	Fine few roots		7.58
BC	110-155	10 YR 5/4 M	sandy loam Sand % - 55.2 Silt% - 22.71 Clay %- 22.09	massive sub angular blocky	slightly hard, friable, slightly sticky and non-plastic;	Fine few roots		7.49
Sikar P-7 (SKR/P-7)								
A1	0-10	10 YR 3/3 M	sandy loam coarse gravel 15-20 per cent Sand % - 77.05	medium, single grain	loose, non-sticky and non-plastic	Few pores coarse gravel 15-20 per cent and fine roots		8.28

			Silt% - 13.6 Clay %- 9.35					
A2	10-22	10 YR 5/6 M	sandy loam coarse gravel >35 Sand % - 78.7 Silt% - 16.7 Clay %- 4.6	medium, single grain	slightly hard, firm, slightly sticky and non-plastic	Medium pores coarse gravel >35 per cent and medium roots		8.09
A3	22-45	7.5 YR 4/6 M	sandy loam Sand % - 79.5 Silt% - 16.2 Clay %- 4.3	medium, single grain	slightly hard, slightly-sticky and non-plastic	Coarse pores coarse gravel >40 per cent and common roots		8.60
A4	45-60	7.5 YR 4/6 M	Loamy sand Sand % - 80.1 Silt% - 12.3 Clay %- 7.6	medium, moderate single grain	slightly hard, firm, slightly-sticky and non-plastic;	Few, medium pores; coarse gravel >45; fine, common roots		8.50
Cr	60+	Weathered rocks	Loamy sand Sand % - 81.05 Silt% - 11.6 Clay %- 7.35					
Sikar P-8 (SKR/P-8)								
Ap	0-12	10 YR 4/6 M	sandy loam Sand % - 75.1 Silt% - 12.4 Clay %- 12.5	fine, single grain	loose, slightly-sticky and non-plastic	Medium pores and common, fine roots		8.23
A1	12-30	10 YR 4/6 M	sandy loam Sand % - 76.2 Silt% - 10.5 Clay %- 13.3	fine, single grain	loose, slightly-sticky and non-plastic	Many, medium pores and common, fine roots;		8.02
A2	30-50	10 YR 4/6 M	loamy sand Sand % - 82.9 Silt% - 9.6 Clay %- 7.5	medium, single grain	loose, slightly-sticky and non-plastic	coarse fragment; medium pores and common roots	slight effervescence	8.32
A3	50-72	10 YR 4/4 M	sandy loam Sand % - 78.1 Silt% - 10.4 Clay %- 11.5	medium, massive	loose, slightly-sticky and non-plastic	many, medium pores and common, medium roots	slight effervescence	8.49
A4	72-93	10 YR 4/4 M	sandy loam Sand % - 77.7 Silt% - 10.5 Clay %- 11.8	medium, massive	loose, slightly-sticky and non-plastic	common, medium pores and medium, fine roots	slight effervescence	8.61
A5	93-115	10 YR 4/4 M	loamy sand Sand % - 81.8 Silt% - 8.4 Clay %- 9.8	medium, massive	loose, slightly-sticky and non-plastic	few, medium pores	slight effervescence	8.60
Sikar P-9 (SKR/P-9)								
Ap	0-20	10 YR 4/2 M	loamy sand Sand % - 87.1 Silt% - 6.4 Clay %- 6.5	fine, massive	slightly hard, slightly-sticky and slightly-plastic	common fine pores and many fine roots	strong effervescence	8.21
A1	20-57	10 YR 5/4M	loamy sand Sand % - 88.4 Silt% - 8.2 Clay %- 3.4	fine, single grain	loose, non-sticky and non-plastic	common, medium pores and common, fine roots	slight effervescence	8.36
A2	57-85	10 YR 7/4 M	Sand Sand % - 88.9 Silt% - 7.9 Clay %- 3.2	fine, single grain	loose, non-sticky and non-plastic	common, medium pores and few fine roots	slight effervescence	8.46
A3	85-100	10 YR 7/4 M	Sand Sand % - 89.6 Silt% - 4.5 Clay %- 5.9	fine, single grain	loose, non-sticky and non-plastic	common, medium pores and few, fine roots	slight effervescence	8.49
A4	100-120	10 YR 7/4 M	Sand Sand % - 90.2 Silt% - 2.1 Clay %- 7.7	fine, single grain	loose, non-sticky and non-plastic	common, medium pores and few, fine roots	slight effervescence	8.51

Physical Properties

The physical properties of soils varied significantly among the studied regions due to differences in soil texture, structure, organic matter content, and degree of profile development. Bulk density values in Sri Ganganagar soils ranged from 1.40 to 1.71 Mg m⁻³ and generally increased with depth, which may be

attributed to compaction and lower organic matter content in subsurface horizons. Udaipur soils recorded comparatively lower bulk density values ranging from 1.18 to 1.27 Mg m⁻³, indicating better aggregation and higher organic matter accumulation. In Sikar soils, bulk density varied from 1.16 to

1.53 Mg m⁻³, with relatively higher values in coarse-textured subsurface layers.

Particle density showed comparatively narrow variation and remained within the normal range for mineral soils. The values ranged from 2.45 to 2.66 Mg m⁻³ in Sri Ganganagar soils, 2.42 to 2.59 Mg m⁻³ in Udaipur soils, and 2.49 to 2.61 Mg m⁻³ in Sikar soils. The relatively uniform particle density indicated similarity in mineralogical composition of the soils.

Water holding capacity (WHC) varied according to texture, structure, and organic carbon content of the soils. In Sri Ganganagar soils, WHC ranged from 24.67 to 40.48 per cent, whereas Sikar soils recorded values between 29.48 and 42.08 per cent. Higher WHC was generally observed in surface horizons and finer-textured soils due to greater clay and organic matter content. The comparatively lower WHC in coarse-textured horizons reflected poor moisture retention capacity of sandy soils.

Porosity exhibited an inverse relationship with bulk density and was higher in finer-textured and well-aggregated soils. Sri

Ganganagar soils recorded porosity values ranging from 34.75 to 42.86 per cent, while Udaipur soils showed comparatively higher porosity ranging from 49.60 to 52.96 per cent. In Sikar soils, porosity varied between 38.55 and 54.86 per cent. Higher porosity in Udaipur soils may be attributed to lower bulk density, better structural development, and comparatively higher organic carbon content.

Overall, the physical properties were strongly influenced by soil texture and organic matter content. Coarse-textured soils of Sri Ganganagar and Sikar districts exhibited relatively higher bulk density, lower porosity, and reduced water holding capacity, characteristics commonly associated with sandy soils of arid and semi-arid regions. In contrast, the Udaipur soils showed lower bulk density, higher porosity, and greater moisture retention due to relatively finer texture and better pedogenic development. These findings are in agreement with earlier reports by Arya *et al.*, (2025), Vedadri and Naidu (2018)^[30], Swarnam *et al.*, (2004)^[28], and Singh and Rathore (2017)^[26].

Table 2: Physical properties: bulk density, particle density, porosity and water holding capacity of soils of major barley growing areas

Profile no.	Horizon	BD (Mg/m ³)	PD(Mg/m ³)	WHC (%)	Porosity (%)
GN/P-1/1	Ap	1.40	2.45	38.15	42.86
GN/P-1/2	Bw1	1.54	2.51	38.02	38.65
GN/P-1/3	Bw2	1.59	2.52	35.12	36.90
GN/P-1/4	Bw3	1.60	2.54	35.09	37.01
GN/P-1/5	Bw4	1.67	2.56	32.28	34.77
	Mean	1.40	2.52	35.73	38.04
GN/P-2/1	Ap	1.50	2.49	34.21	39.76
GN/P-2/2	Bw1	1.58	2.51	33.09	37.05
GN/P-2/3	Bw2	1.64	2.54	31.28	35.43
GN/P-2/4	Bw2	1.66	2.56	29.36	35.16
GN/P-2/5	Bw3	1.67	2.57	27.48	35.02
GN/P-2/6	Bk	1.69	2.59	24.67	34.75
	Mean	1.62	2.54	30.02	36.19
GN/P-3/1	Ap	1.49	2.53	40.48	41.11
GN/P-3/2	Bw1	1.54	2.56	38.97	39.84
GN/P-3/3	Bw2	1.59	2.58	37.12	38.37
GN/P-3/4	Bw3	1.62	2.61	34.19	37.93
GN/P-3/5	Bw4	1.66	2.63	32.48	36.88
GN/P-3/6	Bk	1.71	2.66	31.27	35.71
	Mean	1.59	2.55	33.63	37.44
UDR/P-4/1	A1	1.21	2.46	51.00	50.81
UDR/P-4/2	Bw1	1.23	2.49	50.15	50.60
UDR/P-4/3	Bw2	1.24	2.52	49.34	50.79
UDR/P-4/4	Bw3	1.26	2.53	47.21	50.20
UDR/P-4/5	Cr	1.26	2.54	45.25	50.39
	Mean	1.24	2.51	48.59	50.56
UDR/P-5/1	Ap	1.18	2.42	50.31	51.24
UDR/P-5/2	Bw1	1.19	2.48	48.57	52.02
UDR/P-5/3	Bw2	1.21	2.49	47.20	51.41
UDR/P-5/4	Bw3	1.23	2.52	45.08	51.19
UDR/P-5/5	Bw4	1.25	2.54	44.29	50.79
UDR/P-5/6	BC	1.27	2.52	41.27	49.60
	Mean	1.22	2.50	46.12	51.04
UDR/P-6/1	Ap	1.19	2.53	47.39	52.96
UDR/P-6/2	Bw1	1.20	2.52	44.09	52.38
UDR/P-6/3	Bw2	1.22	2.51	42.66	51.39
UDR/P-6/4	Bw3	1.23	2.53	41.38	51.38
UDR/P-6/5	BC	1.25	2.59	47.25	51.74

	Mean	1.22	2.54	44.55	51.97
SKR/P-7/1	A1	1.42	2.50	42.08	43.20
SKR/P-7/2	A2	1.44	2.51	40.57	42.63
SKR/P-7/3	A3	1.46	2.52	39.57	42.06
SKR/P-7/4	A4	1.50	2.53	34.57	40.74
SKR/P-7/5	Cr	1.52	2.54	33.48	40.16
	Mean	1.47	2.52	38.05	41.76
SKR/P-8/1	Ap	1.39	2.55	40.17	45.49
SKR/P-8/2	A1	1.41	2.56	38.59	44.92
SKR/P-8/3	A2	1.42	2.58	37.61	44.96
SKR/P-8/4	A3	1.44	2.58	35.29	44.19
SKR/P-8/5	A4	1.48	2.59	33.21	42.86
SKR/P-8/6	A5	1.51	2.61	30.28	42.15
	Mean	1.44	2.58	35.86	44.09
SKR/P-9/1	Ap	1.42	2.55	40.07	44.31
SKR/P-9/2	A1	1.45	2.56	38.37	43.36
SKR/P-9/3	A2	1.16	2.57	37.08	54.86
SKR/P-9/4	A3	1.48	2.52	32.18	41.27
SKR/P-9/5	A4	1.53	2.49	29.48	38.55
	Mean	1.41	2.54	35.44	44.47

Physico-Chemical Properties

The chemical properties of the soils varied considerably among locations and profiles. Soil reaction (pH) ranged from 7.1 to 8.9, indicating neutral to strongly alkaline conditions. Sri Ganganagar soils were moderately to strongly alkaline (8.1–8.9), Udaipur soils were near neutral to mildly alkaline (7.1–7.7), and Sikar soils were moderately alkaline (8.0–8.6). The higher pH in Sri Ganganagar and Sikar soils was attributed to calcium carbonate accumulation under arid conditions, whereas the comparatively lower pH of Udaipur soils reflected greater weathering and leaching (Kumar *et al.*, 2022; Arya *et al.*, 2025) [10].

Electrical conductivity (EC) ranged from 0.10 to 0.20 dS m⁻¹ in Sri Ganganagar, 0.10 to 0.70 dS m⁻¹ in Udaipur, and 0.19 to 0.23 dS m⁻¹ in Sikar soils. All the soils were non-saline to slightly saline and remained within safe limits for barley cultivation.

Organic carbon content varied from 0.04 to 0.57 per cent and generally decreased with depth. Udaipur soils recorded

comparatively higher organic carbon (0.37–0.57%), followed by Sikar (0.17–0.29%) and Sri Ganganagar soils (0.04–0.20%). Higher organic carbon in Udaipur soils may be attributed to finer texture and better vegetation cover (Meena *et al.*, 2012; Singh and Rathore, 2017) [14, 26].

Exchangeable sodium, potassium, calcium, and magnesium ranged from 0.03–1.47, 0.10–0.59, 2.50–19.22, and 1.17–9.89 meq 100 g⁻¹, respectively. Calcium was the dominant exchangeable cation, followed by magnesium, sodium, and potassium. Cation exchange capacity (CEC) ranged from 5.1 to 43.2 meq 100 g⁻¹ and was generally higher in Sri Ganganagar and Udaipur soils. Exchangeable calcium and magnesium increased with depth in Sri Ganganagar and Sikar soils due to carbonate accumulation and limited leaching (Singh and Rathore, 2015; Arya *et al.*, 2025) [25]. Higher CEC and exchangeable bases in Udaipur soils were associated with greater clay and organic matter content, resulting in better nutrient retention capacity (Meena *et al.*, 2012; Kumar *et al.*, 2022) [14, 10].

Table 3: Physico-Chemical Properties and Exchangeable Cations of Soil Profiles from Sri Ganganagar, Udaipur, and Sikar Districts

Horizon	Depth	pH (1:2.5 soil water suspension)	EC (dSm-1)(1:2.5 soil water suspension)	Organic C (%)	Na meq/ 100g	K meq/ 100g	Ca meq/100 gm of soil	Mg meq/100g of soil (tit)	SUM	CEC
Sri Ganganagar P-1 (GN/P-1)										
Ap	0-20	8.6	0.11	0.16	0.05	0.17	7.18	3.20	10.61	13.97
Bw1	20-38	8.7	0.12	0.15	0.03	0.16	8.24	4.40	12.83	19.21
Bw2	38-75	8.5	0.10	0.13	0.05	0.15	8.82	6.00	15.02	26.20
Bw3	75-106	8.5	0.11	0.11	0.07	0.16	9.23	8.25	17.71	36.03
Bw4	106-150	8.4	0.13	0.09	0.07	0.14	9.34	9.68	19.23	42.27
Mean		8.5	0.11	0.13	0.06	0.16	8.56	6.31	15.08	27.54
Sri Ganganagar P-2 (GN/P-2)										
Ap	0-19	8.9	0.13	0.20	0.09	0.29	12.31	6.40	19.09	27.95
Bw1	19-43	8.8	0.15	0.15	0.10	0.25	13.60	7.20	21.15	31.44
Bw2	43-82	8.7	0.11	0.14	0.12	0.23	14.28	7.98	22.61	34.85
Bw2	82-112	8.7	0.20	0.12	0.11	0.24	14.97	8.56	23.88	37.38
Bw3	112-147	8.6	0.10	0.10	0.14	0.19	16.37	8.80	25.50	38.43
Bk	147-160	8.4	0.12	0.08	0.17	0.15	17.28	9.20	26.80	40.17
Mean		8.3	0.14	0.13	0.12	0.23	14.80	8.02	23.17	35.04

Sri Ganganagar P-3 (GN/P-3)										
Ap	0-20	8.5	0.13	0.15	1.21	0.21	14.24	3.21	18.87	14.02
Bw1	20-50	8.4	0.11	0.12	0.93	0.19	15.94	4.39	21.45	19.17
Bw2	50-90	8.3	0.12	0.11	1.18	0.18	16.24	5.20	22.80	22.71
Bw3	90-125	8.2	0.10	0.09	1.24	0.17	17.19	6.24	24.84	27.25
Bw4	125-153	8.2	0.12	0.07	1.28	0.14	18.29	7.41	27.12	32.36
Bk	153-165	8.1	0.10	0.06	1.31	0.12	19.22	8.57	29.22	37.42
Mean		8.5	0.12	0.12	0.44	0.19	13.48	6.79	20.89	29.65
Udaipur P-4 (UDR/P-4)										
A1	0-25	7.2	0.59	0.57	0.10	0.19	11.21	4.31	15.8	18.8
Bw1	25-50	7.1	0.68	0.53	0.12	0.26	12.45	5.02	17.9	21.9
Bw2	50-85	7.3	0.46	0.50	0.04	0.29	13.25	6.21	19.8	27.1
Bw3	85-110	7.2	0.70	0.42	0.24	0.26	14.14	9.89	24.5	43.2
Cr	110+	7.4	0.38	0.41	0.07	0.38	16.80	9.87	27.1	43.1
Mean		7.3	0.56	0.49	0.11	0.28	13.57	7.06	21.02	30.83
Udaipur P-5 (UDR/P-5)										
Ap	0-21	7.6	0.29	0.52	0.10	0.47	16.99	6.45	24.0	28.2
Bw1	21-48	7.4	0.19	0.51	0.12	0.40	17.45	7.45	25.4	32.5
Bw2	48-82	7.5	0.38	0.45	0.98	0.19	17.59	7.14	25.9	31.2
Bw3	82-100	7.3	0.10	0.42	0.11	0.28	16.58	6.98	24.0	30.5
Bw4	100-160	7.5	0.21	0.38	1.27	0.59	15.47	8.83	26.2	38.6
BC	160+	7.5	0.58	0.37	0.17	0.42	16.80	8.99	26.4	39.3
Mean		7.5	0.29	0.45	0.46	0.39	16.81	7.64	25.30	33.36
Udaipur P-6 (UDR/P-6)										
Ap	0-20	7.7	0.54	0.50	1.21	0.25	16.00	7.02	24.5	30.7
Bw1	20-45	7.7	0.21	0.51	0.45	0.19	15.19	7.98	23.8	34.8
Bw2	45-80	7.7	0.39	0.51	0.69	0.31	16.25	5.47	22.7	23.9
Bw3	81-110	7.5	0.48	0.47	1.02	0.25	14.47	4.24	20.0	18.5
BC	110-155	7.4	0.56	0.42	0.84	0.22	16.47	6.45	24.0	28.2
Mean		7.6	0.44	0.48	0.84	0.24	15.68	6.23	22.99	27.21
Sikar P-7 (SKR/P-7)										
A1	0-10	8.2	0.21	0.29	0.06	0.22	3.56	1.19	5.0	5.2
A2	10-22	8.0	0.23	0.28	0.04	0.26	4.51	2.02	6.8	8.8
A3	22-45	8.6	0.19	0.21	0.08	0.37	3.74	1.28	5.5	5.6
A4	45-60	8.5	0.20	0.21	0.20	0.12	4.20	3.48	8.0	15.2
Cr	60+	8.0	0.20	0.21	0.58	0.38	3.53	1.17	5.7	5.1
Mean		8.3	0.21	0.24	0.19	0.27	3.91	1.83	6.20	7.98
Sikar P-8 (SKR/P-8)										
Ap	0-12	8.2	0.21	0.27	0.74	0.47	6.45	6.14	13.8	26.8
A1	12-30	8.0	0.23	0.25	0.45	0.24	9.40	4.70	14.8	20.5
A2	30-50	8.3	0.19	0.23	1.47	0.19	7.15	5.18	14.0	22.6
A3	50-72	8.4	0.21	0.21	0.59	0.28	4.70	4.14	9.7	18.1
A4	72-93	8.6	0.20	0.21	0.87	0.15	4.17	2.90	8.1	12.7
A5	93-115	8.6	0.22	0.2	0.17	0.10	8.35	1.20	9.8	5.2
Mean		8.3	0.21	0.23	0.72	0.24	6.70	4.04	11.70	17.66
Sikar P-9 (SKR/P-9)										
Ap	0-20	8.2	0.21	0.23	1.25	0.39	6.89	6.48	15.0	28.3
A1	20-57	8.3	0.23	0.22	0.98	0.19	8.20	3.50	12.9	15.3
A2	57-85	8.4	0.22	0.19	0.69	0.44	6.40	1.30	8.8	5.7
A3	85-100	8.4	0.21	0.17	1.02	0.25	3.80	3.18	8.3	13.9
A4	100-120	8.5	0.19	0.17	0.84	0.11	2.50	4.10	7.6	17.9
Mean		8.4	0.21	0.20	0.96	0.28	5.56	3.71	10.50	16.21

Available nitrogen, phosphorus, and potassium varied considerably among the soil profiles, ranging from 94.58–315.25, 9.47–24.40, and 108.47–248.43 kg ha⁻¹, respectively. Higher nutrient availability was observed in Udaipur soils, while comparatively lower values were recorded in Sri Ganganagar and Sikar soils. Available nutrient contents generally decreased with soil depth. DTPA-extractable zinc, iron, copper, and manganese ranged from 0.31–0.60, 1.97–5.03, 0.15–1.52, and 1.94–7.36 mg kg⁻¹, respectively. Relatively higher micronutrient availability was found in Udaipur and

Sikar soils. The distribution of macro- and micronutrients was largely influenced by soil texture, organic carbon content, and soil reaction. Higher nutrient availability in Udaipur soils may be attributed to favourable texture, greater organic carbon content, and near-neutral pH, whereas the coarse-textured and alkaline soils of Sri Ganganagar and Sikar exhibited lower nutrient availability due to poor nutrient retention and low organic matter content (Meena *et al.*, 2012; Singh and Rathore, 2015; Dutta *et al.*, 2017; Gogoi *et al.*, 2018) [14, 25, 7, 8].

Table 4: Horizon-Wise Available Macronutrients and Micronutrient Status of Soil Profiles from Sri Ganganagar, Udaipur, and Sikar Districts

Horizon	Depth	N (Kg ha ⁻¹)	P2O5(Kg ha ⁻¹)	K2O (Kg ha ⁻¹)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)
Sri Ganganagar P-1 (GN/P-1)								
Ap	0-20	197.46	19.45	237.91	0.45	3.11	0.31	5.51
Bw1	20-38	173.24	17.28	212.64	0.40	2.72	0.28	4.78
Bw2	38-75	141.29	16.22	175.91	0.43	2.54	0.24	4.12
Bw3	75-106	121.39	14.29	146.29	0.39	2.61	0.21	3.45
Bw4	106-150	102.37	13.24	132.59	0.31	1.97	0.18	3.09
Mean		147.15	16.10	181.07	0.40	2.59	0.24	4.19
Sri Ganganagar P-2 (GN/P-2)								
Ap	0-19	178.94	20.73	248.43	0.54	5.03	0.78	3.61
Bw1	19-43	161.33	19.87	212.14	0.51	5.71	0.64	3.57
Bw2	43-82	145.29	18.08	198.37	0.49	5.41	0.61	3.42
Bw2	82-112	131.09	16.29	182.39	0.41	5.08	0.52	2.84
Bw3	112-147	112.29	15.29	163.94	0.37	4.27	0.41	2.45
Bk	147-160	101.32	13.02	142.36	0.39	3.94	0.36	2.13
Mean		138.38	17.21	191.27	0.45	4.91	0.55	3.00
Sri Ganganagar P-3 (GN/P-3)								
Ap	0-20	184.48	18.24	222.67	0.42	3.96	0.27	4.12
Bw1	20-50	178.49	16.31	204.37	0.49	3.75	0.23	4.13
Bw2	50-90	142.97	14.29	184.29	0.48	3.49	0.24	3.67
Bw3	90-125	121.09	12.28	162.16	0.38	3.34	0.21	2.48
Bw4	125-153	102.33	10.59	132.59	0.34	2.31	0.18	2.20
Bk	153-165	94.58	9.47	108.47	0.42	1.98	0.15	1.94
Mean		140.81	15.70	181.05	0.42	3.62	0.35	3.41
Udaipur P-4 (UDR/P-4)								
A1	0-25	285.26	21.027	227.657	0.48	4.482	1.347	6.770
Bw1	25-50	283.47	21.490	221.646	0.47	4.457	1.431	7.005
Bw2	50-85	281.41	21.627	215.956	0.47	4.799	1.423	6.986
Bw3	85-110	280.09	21.945	220.636	0.46	4.061	1.315	7.235
Cr	110+	279.51	22.257	227.131	0.45	4.371	1.318	6.605
Mean		281.95	21.67	222.61	0.47	4.43	1.37	6.92
Udaipur P-5 (UDR/P-5)								
Ap	0-21	315.25	22.511	230.629	0.60	4.573	1.420	7.069
Bw1	21-48	305.14	24.326	222.915	0.60	4.426	1.450	7.151
Bw2	48-82	302.17	23.278	217.895	0.59	4.893	1.383	6.960
Bw3	82-100	298.85	23.337	225.881	0.59	4.061	1.326	7.356
Bw4	100-160	293.87	22.977	229.395	0.58	4.141	1.346	6.576
BC	160+	285.49	23.411	231.782	0.57	4.546	1.424	6.707
Mean		300.13	23.31	226.42	0.59	4.44	1.39	6.97
Udaipur P-6 (UDR/P-6)								
Ap	0-20	302.14	23.607	233.849	0.52	4.536	1.433	7.109
Bw1	20-45	299.45	24.068	220.856	0.52	4.753	1.499	7.144
Bw2	45-80	295.48	23.175	222.677	0.51	4.277	1.299	7.135
Bw3	81-110	292.15	23.312	220.452	0.50	4.189	1.328	6.976
BC	110-155	291.01	23.195	220.750	0.49	4.556	1.392	6.789
Mean		296.05	23.47	223.72	0.51	4.46	1.39	7.03
Sikar P-7 (SKR/P-7)								
A1	0-10	159.78	19.67	225.85	0.47	4.371	1.376	7.18
A2	10-22	150.74	21.70	228.03	0.45	4.573	1.486	7.22
A3	22-45	156.67	21.32	215.87	0.47	4.426	1.210	6.90
A4	45-60	153.92	22.25	217.59	0.46	4.893	1.334	6.92
Cr	60+	149.52	21.02	223.99	0.41	4.061	1.445	5.14
Mean		154.13	21.19	222.27	0.45	4.46	1.37	6.67
Sikar P-8 (SKR/P-8)								
Ap	0-12	154.78	21.95	227.45	0.44	4.141	1.210	7.17
A1	12-30	152.02	22.20	233.66	0.41	4.546	1.334	6.88
A2	30-50	147.58	23.99	215.87	0.48	4.446	1.445	6.89
A3	50-72	144.32	24.40	218.24	0.52	4.416	1.373	6.99
A4	72-93	134.52	22.35	225.56	0.42	4.409	1.523	6.25
A5	93-115	130.47	22.20	231.32	0.44	4.546	1.291	5.33
Mean		143.95	22.85	225.35	0.45	4.42	1.36	6.58
Sikar P-9 (SKR/P-9)								
Ap	0-20	157.32	23.02	233.38	0.46	4.619	1.412	7.017
A1	20-57	157.10	23.56	215.91	0.50	4.669	1.450	6.929
A2	57-85	152.23	24.02	219.60	0.49	4.327	1.418	6.933
A3	85-100	138.17	22.65	225.79	0.42	4.706	1.227	7.197
A4	100-120	129.58	22.99	232.12	0.45	4.631	1.317	6.586
Mean		146.88	23.25	225.36	0.46	4.59	1.36	6.93

Evaluation of Soils for Land Capability, Irrigability and Suitability for Barley

Land Capability Classification

Land capability classification placed Sri Ganganagar soils under Classes III_s, III_{e,s}, and IV_{s,e} due to coarse texture, excessive drainage, alkalinity, low organic carbon, and erosion hazards. Udaipur soils were classified under Classes II and III_{ws}, reflecting favourable soil and drainage conditions in most profiles, while limitations such as clayey texture, occasional flooding, and alkalinity restricted some areas. Sikar soils belonged to Classes III_{ws} and IV_s because of coarse texture, shallow depth, erosion risk, and alkaline reaction. Overall, the predominance of Classes III and IV in Sri Ganganagar and Sikar indicates moderate to severe land-use limitations, whereas the occurrence of Class II in Udaipur reflects comparatively better agricultural capability (Singh and Rathore, 2017; Mandal *et al.*, 2017; Arya *et al.*, 2025) ^[26, 13].

Irrigability Classification

Irrigability classification indicated considerable variation among the studied soils. Sri Ganganagar soils were classified under Classes 3(s) and 4(s,t) due to coarse texture, excessive drainage, low waterholding capacity, and alkalinity. Udaipur soils belonged to Classes 1 and 2, reflecting favourable texture, adequate soil depth, and near-neutral soil reaction, although some profiles showed limitations of clayey texture, salinity, and slight alkalinity. Sikar soils were grouped under Classes 3 and 4 because of shallow depth, coarse texture, excessive drainage, and moderate alkalinity. Overall, the irrigability of Sri Ganganagar and Sikar soils was constrained by sandy texture and poor moisture retention, whereas Udaipur soils exhibited comparatively better irrigability due to favourable physical and chemical properties (Patel *et al.*, 2018; Yadav *et al.*, 2019; Arya *et al.*, 2025) ^[21, 33].

Table 5: Land Capability Classification (LCC) of Soils in Major Barley Growing Areas of Rajasthan

Profile No.	Location	Slope (%)	Erosion	Drainage	Limiting Factors	LCC Class
GN/P -1	Sri Ganganagar	3-8	Severe	Excessive	Slope, erosion, texture, alkalinity	Ives
GN/P -2	Sri Ganganagar	0-1	Very slow	Medium well	Coarse texture, alkalinity	III _{ws}
GN/P -3	Sri Ganganagar	1-3	Moderate	Well	Slight erosion, coarse texture, alkalinity	III _{ws}
UDR/P-4	Udaipur	0-1	Slight	Moderately well	None to slight limitations	II
UDR/P-5	Udaipur	3-5	Slight	Moderately well	High clay, occasional flooding, alkalinity	III _{ws}
UDR/P-6	Udaipur	1-3	Slight	Moderately well	Slight alkalinity, coarse texture	II
SKR/P-7	Sikar	3-8	High	Extensively drained	Erosion, slope, shallow depth, coarse texture	Ives
SKR/P-8	Sikar	0-1	Moderate	Well drained	Coarse texture, alkalinity	III _{ws}
SKR/P-9	Sikar	0-1	Moderate	Well drained	Coarse texture, alkalinity	III _{ws}

Table 6: Irrigability Classification of Soils in Major Barley Growing Areas of Rajasthan

Profile No.	Texture (Topsoil)	Soil Depth (cm)	Drainage	pH	EC (dSm-1)	Limiting Factors	Irrigability Class
GN/P -1	Sand	>150	Excessive	8.53	0.11	Coarse texture, low WHC, rapid drainage, low organic carbon	4
GN/P -2	Sandy loam	>160	Medium well	8.32	0.14	Slight alkalinity, moderate salinity, declining nutrients with depth	3
GN/P -3	Sandy loam	>165	Well	8.51	0.12	High alkalinity, coarse texture, low micronutrient status in lower horizons	3
UDR/P-4	Sandy clay loam	>110	Moderately well	7.30	0.56	None	1
UDR/P-5	Clay	>160	Moderately well	7.52	0.29	High clay content, occasional flooding	2
UDR/P-6	Sandy loam	>155	Moderately well	7.67	0.44	Slight alkalinity, medium salinity	2
SKR/P-7	Sandy loam	>60	Extensively drained	8.30	0.21	Shallow depth, high erosion	4
SKR/P-8	Sandy loam	>115	Well drained	8.38	0.23	Coarse texture	3
SKR/P-9	Loamy sand	>120	Well drained	8.41	0.20	Coarse texture, slight alkalinity	3

Soil-Site Suitability for Barley

Soil-site suitability evaluation for barley revealed that Udaipur soils were classified as Highly Suitable (S1) to Moderately Suitable (S2) due to favourable texture, adequate depth, good drainage, near-neutral pH, and higher nutrient availability. Sri Ganganagar soils belonged to Moderately Suitable (S2) and Marginally Suitable (S3) classes, while Sikar soils were grouped under S2 and S3 categories. The limitations affecting

suitability in Sri Ganganagar and Sikar included coarse texture, alkalinity, low organic carbon content, shallow depth, excessive drainage, and lower nutrient availability. Overall, Udaipur soils exhibited the highest suitability for barley cultivation, whereas Sri Ganganagar and Sikar soils were constrained by physical and chemical limitations (Choudhary *et al.*, 2019; Kumawat *et al.*, 2021; Yadav *et al.*, 2021) ^[6, 11, 34].

Table 7: Soil-Site Suitability Classification for Barley in Major Barley Growing Areas of Rajasthan

Profile No.	Texture (Topsoil)	Soil Depth (cm)	Drainage	Ph	EC (dSm-1)	Limiting Factors	Available N (kg ha-1)	Available P (kg ha-1)	Available K (kg ha-1)	Suitability Class
GN/P -1	Sand	>150	Excessive	8.53	0.11	Coarse texture, low WHC, rapid drainage, low organic carbon	127.15	13.10	141.07	S3
GN/P -2	Sandy loam	>160	Medium well	8.32	0.14	Slight alkalinity, moderate salinity, declining nutrients with depth	138.38	17.21	191.27	S2
GN/P -3	Sandy loam	>165	Well	8.51	0.12	High alkalinity, coarse texture, low micronutrient status in lower horizons	140.81	15.70	181.05	S2
UDR/P-4	Sandy clay loam	>110	Moderately well	7.30	0.56	None	281.95	20.10	300.50	S1
UDR/P-5	Clay	>160	Moderately well	7.52	0.29	High clay content, occasional flooding	300.13	18.20	280.20	S2
UDR/P-6	Sandy loam	>155	Moderately well	7.67	0.44	Slight alkalinity, medium salinity	296.05	19.90	285.30	S1
SKR/P-7	Sandy loam	>60	Extensively drained	8.30	0.21	Shallow depth, high erosion	154.13	11.30	142.50	S3
SKR/P-8	Sandy loam	>115	Well drained	8.38	0.23	Coarse texture	143.95	13.80	150.40	S2
SKR/P-9	Loamy sand	>120	Well drained	8.41	0.20	Coarse texture, slight alkalinity	146.88	12.90	148.30	S2

Conclusions

The study demonstrated considerable variability in the morphological, physical, physico-chemical, and fertility characteristics of soils from the major barley-growing regions of Rajasthan. Udaipur soils exhibited better profile development, finer texture, higher organic carbon content, and greater nutrient availability, resulting in higher land capability, better irrigability, and suitability classes ranging from S1 to S2 for barley cultivation. In contrast, the soils of Sri Ganganagar and Sikar were predominantly coarse-textured, moderately alkaline, and low in organic carbon and available nutrients, leading to lower land capability and moderate to marginal suitability (S2–S3). Soil texture, depth, drainage, alkalinity, and nutrient status were identified as the key factors governing barley suitability. The findings emphasize the importance of integrated soil management practices, including organic matter addition, balanced nutrient application, and alkalinity management, to enhance soil productivity and ensure sustainable barley cultivation in the arid and semi-arid regions of Rajasthan.

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