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FULL-LENGTH RESEARCH ARTICLE

# Identifying Sensitive Soil Properties as a Function of Land Use Change in Thar Desert of India

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**Abstract** Soil plays a critical role in earth's biosphere by supporting the production of food, fodder and fiber. However, rapid land use changes in recent times in different parts of the world led to increasing concern on soil health. It has been realized that changes in land use systems significantly affect soil properties. Therefore, we studied the impact of land use systems on soil physicochemical properties in the Thar Desert of India. Surface soil samples (0–30 cm) from four land use systems: (1) sand dunes, (2) grazing lands, (3) rainfed croplands and (4) irrigated croplands have been collected and analyzed in laboratory to determine soil pH, electrical conductivity (EC), $CaCO_3$ content, organic carbon content, available P content, available K content and micronutrients (Zn, Fe, Mn, and Cu) content. We observed higher clay, organic carbon and nutrient contents and lower bulk density values in irrigated croplands than in other land use systems. Soil pH and EC were higher in irrigated croplands than in the other land use systems. Principal component analysis of soil physicochemical properties revealed two major soil factors, the clay–carbon factor and salinity factor, which were able to significantly differentiate the land use systems. For irrigated croplands, the clay–carbon factor was found to be higher than the rest of the land uses; however, the salinity factor was the lowest. Higher values of these two factors will lead to a favorable soil physicochemical environment for plant growth or better soil health. These two factors may further be used for assessing the impact of land use systems on soil quality in other regions.

**Keywords** Arid soils · Land use systems · Soil properties · Organic carbon

## Introduction

As civilization and the resulting demand for food kept progressing, there was a tendency to rapidly convert native land use systems to agricultural use in different parts of the world. Predominantly, area under irrigated agriculture has been tremendously increased with the advent of efficient irrigation techniques like drip and sprinkler irrigation systems even in arid regions. Such forcible land use changes are certainly having an impact on ecosystem, which may either be positive or negative. Therefore, proper management of ecosystem components with specific focus on soil resources under changing land use scenarios is essential. Moreover, under the context of climate change, alternate land use systems can be considered as mitigating, but understanding the potential impact of land use changes over time on soil resources is essential.

Interest in evaluating soil quality has been further stimulated by an increasing awareness of the critical role of soil for sustaining earth biosphere [6]. Maddoni et al. [19] reported a strong effect of land use changes on the basic soil and landscape processes such as soil erosion, soil structure, nutrient recycling, carbon sequestration. Intensive agricultural practices, in general, are well known to cause changes in soil physical, chemical and biological properties [16]. However, the dynamics and magnitude of

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such changes depend on inherent soil characteristics and their resilience. Studies have reported the impact of land use conversion on soil physicochemical properties; however, similar studies in arid areas are limited specifically in fragile soil ecosystem of Indian Thar Desert where a very rapid change in land use systems has been observed during last few decades. Input intensive agricultural practices, for example, application of nitrogenous fertilizer, irrigation water, organic residues and manures in the desert of South Central Senegal have been reported to enhance soil fertility [33]. Introduction of efficient irrigation practices in desert areas of Iran has been reported to increase organic carbon, total nitrogen, carbohydrate and particulate organic carbon [8]. Similarly, increase in nitrogen, phosphorus and potassium content of soil due to introduction of modern agricultural practices has also been reported for the arid region of Jordan [1].

In India, the hot arid ecosystem covers an area of 32 million ha and is located at northwestern part of the country, out of which 62% area lies in western Rajasthan covering 12 districts. The major landforms in arid western Rajasthan are dune and inter-dune plains, which are either sandy or sandy loam in texture. Ambient air temperature of the region remains high for most of the year and reaches up to 42–45 °C during summer months (April–July), whereas annual rainfall is very low and sporadic (200–400 mm) and mainly occurs during monsoon season from August to September. Annual potential evapotranspiration ranges from 1500 to 2000 mm. Loss of top fertile soil from denuded surface through wind erosion is frequent during summer months. Frequent occurrence of droughts in the region, once in every 3 years, further intensifies the process of desertification [26]. During the last few decades, a twofold to threefold increase in irrigated areas with cultivation of both rainfed crops (*kharif*) and irrigated crops (*rabi*) has been recorded and most of these increments are through land use changes from rainfed cultivation, grazing areas and sand dunes to irrigated cultivation. Overall, the net irrigated area in Rajasthan has been recently in 2012 reported as 5.84 million ha and about 74% of this area is irrigated through wells and tube wells. Keeping in mind this significant land use change in western Rajasthan and its potential effect on soil resources, we attempted to evaluate its impact on soil resources under four major land use systems in a selected district, from the region. Soil physicochemical properties under four major land use systems, e.g., irrigated agriculture, rainfed agriculture, grassland or grazing lands and sand dunes in the Jhunjhunu district from western Rajasthan were evaluated through principal component analysis.

## Materials and Methods

### Study Area

The present study was carried out in Jhunjhunu district, which covers an area of 5928 km$^2$ and lies at northeastern fringe of Thar Desert of India between 27°38′15″–28°31′14″N and 75°01′32″–75°05′51″E (Fig. 1). Elevation throughout the district varies from 300 to 450 m above mean sea level. Mean annual rainfall of the district is 444.5 mm with a decreasing trend of 484 mm to 331 mm from east to west. Major portion of the annual rainfall is received during summer monsoon from July to September in about 26–32 rainy days. Mean potential annual evapotranspiration is 1578 mm, which always exceeds the annual precipitation, and thus the length of the growing season is very short in the region. Mean daily maximum and minimum temperatures in a year are 45 and 23 °C, respectively. Occasionally, minimum temperature dips below 0 °C at few places during winter season. Soils of the district are coarse in texture, light brown, very deep, non-calcareous, drainable and taxonomically classified as Typic Torripsamments (Arenosols), Typic Torrifluvents (Fluvisols) and Typic Haplocambid (Xerosols and Solonchaks) as per USDA soil taxonomy. Pearl millet (*Pennisetum glaucum*), cluster bean (*Cyamopsis tetragonoloba*), moth bean (*Vigna aconitifolia*), moong bean (*Vigna radiata*) and sesamum (*Sesamum indicum*) are the major crops grown in the district. Wheat (*Triticum sp*) and mustard (*Brassica sp.*) are grown with irrigation from groundwater resources, while chick pea (*Cicer arietinum)* and taramira (*Eruca sativa*) are cultivated with the support of conserved soil moisture and winter rains.

In the Jhunjhunu district, agriculture is the dominant land use comprising 84.4% area of the district under both irrigated and rainfed croplands. Irrigated croplands are cultivated twice in a year with the help of irrigation facilities both during monsoon season (*kharif*) and winter season (*rabi*), whereas rainfed croplands are cultivated only once in a year with the available rainwater during *kharif* season. Permanent pasture/grazing lands, wastelands, forest, settlement and water bodies are the rest of the land use systems contributing to 4.4, 1.9, 6.4 and 2.9% area of the district, which is about 260.8, 112.6, 379.4 and 171.9 km$^2$, respectively.

### Field Sampling and Laboratory Analysis

Surface soil samples (0–30 cm) from 252 locations in Jhunjhunu district were collected representing major land uses of the district, e.g., sand dunes, grazing lands, rainfed crop lands and irrigated crop lands. Locations of the

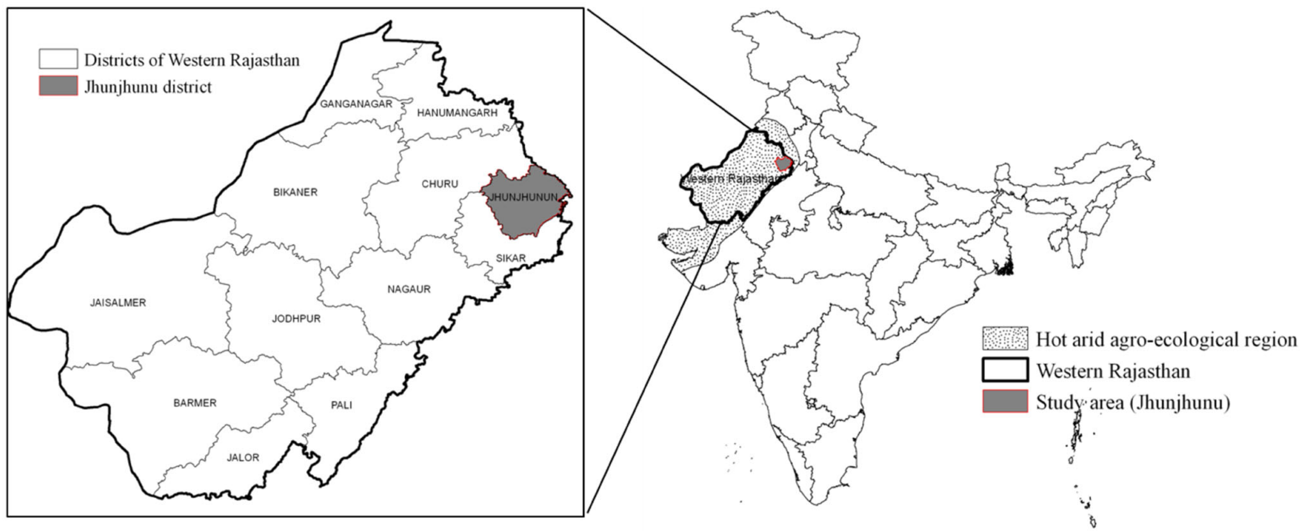



**Fig. 1** Location of study area, Jhunjhunu district in western Rajasthan lying over hot arid agro-ecological region of India

sampling places were recorded with the help of global positioning system (GPS). The soil samples were then processed for physical and chemical analysis. Soil reaction or pH was determined by pH meter using soil/water suspensions prepared in a 1:2 ratio. Soil EC was determined using conductivity bridge [11]. Organic carbon and $CaCO_3$ content in soils were estimated following the methods proposed by Walkley and Black [31] and Piper [23]. Available phosphorus content was determined by Olsen extraction method [22] and available potassium content by flame photometer after extraction with 1 N ammonium acetate solution at pH 7.0. Micronutrient contents of soil samples (Zn, Fe, Mn, and Cu) were determined first by extracting with DTPA reagent [18] and then by analyzing the content using atomic absorption spectrophotometer (GBC-932 AA). Soil textural analysis was carried out by international pipette method [23] using sodium hexametaphosphate as a dispersing agent. Bulk density was determined by collecting undisturbed soil cores of 4.9 cm diameter and 4.9 cm height. In loose sandy soils, it was difficult to collect undisturbed soil cores using conventional core sampler. To avoid the problem, the sampling site was pre-wetted before collecting the cores from different soil layers so that soils inside the core remain undisturbed. Collected soil cores were oven-dried and weighed to calculate oven-dry bulk density [3]. During oven drying, undisturbed cores were placed on a pre-weighted aluminum lid so that dried soil did not fall out of the core while it was weighed.

Fifteen water samples from the area where soils were irrigated with ground water and affected by sodicity were collected for detailed laboratory investigation. Water samples were analyzed for cations and anions using standard method [25]. The $Ca^{+2}$ and $Mg^{+2}$ were analyzed by Versenate titration method, Na and K by flame photometer and $Cl^{-1}$, $SO_4^{-2}$, $CO_3^{-2}$, $HCO_3^{-1}$ by standard titration methods. The sodium absorption ratio (SAR) and residual sodium carbonate (RSC) were calculated using formula given below:

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\mathrm{Ca}^{+2} + \mathrm{Mg}^{+2}/2}} \tag{1}$$

where Na, Ca, Mg are in me $L^{-1}$;

$$\mathrm{RSC}\left(\mathrm{me\,L}^{-1}\right) = \left(\mathrm{CO}_3^{-2} + \mathrm{HCO}_3^{-1}\right) - \left(\mathrm{Ca}^{+2} + \mathrm{Mg}^{+2}\right) \tag{2}$$

## Data Analysis

Descriptive statistics of soil properties, e.g., mean, standard deviation, range and correlation matrix were calculated. Principal component analysis of soil properties was carried out to identify the major components, which were further correlated with land use system of Jhunjhunu district. The principal component function of R was used for principal component analysis, and correlation matrix was used in the analysis. Classical covariance matrix was also used as an input in the principal component function. In the principal component function, original data are first transformed through subtracting by mean and divided by standard deviation. Eigenvalues from the principal component analysis were used to calculate the variances explained by orthogonal components. Eigenvectors obtained from the principal component analysis using principal component function indicate the correlation coefficients between soil properties and derived orthogonal components, which are also known as loading factor. These loading factors along with the center and scale of the transformed data were further used to calculate the PC scores of a test data with known PC score. All other statistical analyses were carried out in R software [24].

## Results

### Soil Physicochemical Properties Under Different Land Uses

Descriptive statistics of soil properties are presented in Table 1. Histogram plots of soil properties are presented in Fig. 2. Except EC and $CaCO_3$ content, soil properties were found normally distributed and hence log-normal transformation was carried out on these two soil properties. Few outliers from the dataset were also removed after exploring the data distributions for each soil property. Comparative analysis of soil properties across different land use systems is also presented in Figs. 3 and 4. Overall, it has been observed that soils are sandy to sandy loam in texture with average clay content of 7.17% and ranging between 3.0 and 12.8% (Table 1). Among different land uses, clay content was observed significantly higher ($p < 0.05$) in irrigated croplands than rest of the land uses (Fig. 3a). Bulk density was observed significantly higher ($p < 0.05$) in sand dunes than rainfed crop lands, grazing lands and irrigated crop lands (Fig. 3b). Soils were found alkaline in reaction with pH value ranging from 8.1 to 9.2. Continuous irrigation practices as well as the poor quality of ground water used for irrigation affected soil pH significantly. The electrical conductivity of water samples ranged from 0.52 to 4.2 dS $m^{-1}$ with a mean value of 2.10 dS $m^{-1}$. The pH of water varied from 7.89 to 9.10. Most of the water samples had pH above 8.50, indicating high sodicity in water (Table 2). Among the cations, Na is by far the dominant followed by Mg and Ca. In case of anions, they are present in order of $Cl^{-1} > HCO_3^{-1} > CO_3^{-2}$. Most of the water samples lie under high chloride class. The residual sodium carbonate values ranged from 0.60 to 14.80 me $L^{-1}$. However, irrigation with these waters for a long period leads to sodicity in soils, as reflected by the pH values of soils. Soils under irrigated croplands were significantly higher in pH ($p < 0.05$) than rainfed croplands and grazing lands (Fig. 3c). Soil EC varied from 0.02 to 1.15 dS $m^{-1}$ and thus most of the soil samples were found in normal range [21]. EC was highest in irrigated cropland and lowest in sand dunes and showed significant differences across land use systems (Fig. 3d). $CaCO_3$ content was found below 1% for most soil samples with average content of 0.59%; however, high content (5–6%) was observed for few soil samples. Comparatively, $CaCO_3$ content was statistically similar across different land use systems (Fig. 3e). Average OC content of soils has been observed as 0.13% with a range of 0.03–0.45%. Organic carbon (OC) content of soils was observed highest under irrigated crop lands ($p < 0.05$) followed by grazing lands and rainfed crop lands and lowest in sand dunes (Fig. 3f). Lowest OC in dunes may partly be due to low ground coverage through vegetation and thus less addition of biomass residue on soil surface. OC content in irrigated croplands was about 175, 75 and 47% higher than dunes, rainfed croplands and grazing lands, respectively. Available P content in soils showed wide variability with a range between 3.5 and 28.5 kg $ha^{-1}$. Phosphorus content was significantly higher ($p < 0.05$) under irrigated croplands than sand dunes (Fig. 4a). Higher content of available P in irrigated

**Table 1** Soil physicochemical properties in Jhunjhunu district

| Soil properties | Mean | Standard deviation | Range |
|---|---|---|---|
| Sand (%) | 87.16 | 5.06 | 77.30–94.30 |
| Silt (%) | 5.67 | 3.37 | 1.70–10.60 |
| Clay (%) | 7.17 | 2.15 | 3.0–12.8 |
| Bulk density (Mg $m^{-3}$) | 1.58 | 0.02 | 1.54–1.61 |
| pH | 8.40 | 0.28 | 8.1–9.2 |
| log [EC (dS $m^{-1}$)] | − 2.16 | 0.77 | − 3.91 to 0.14 |
| log [$CaCO_3$ (%)] | − 1.69 | 1.51 | − 3.91 to 1.76 |
| Organic Carbon (%) | 0.13 | 0.07 | 0.03–0.45 |
| Available P (kg $ha^{-1}$) | 12.16 | 8.04 | 3.5–28.5 |
| Available K (kg $ha^{-1}$) | 177.3 | 89.11 | 84–442 |
| DTPA-extractable Fe (mg $kg^{-1}$) | 7.13 | 3.90 | 3.8–16.5 |
| DTPA-extractable Mn (mg $kg^{-1}$) | 11.17 | 4.62 | 3.60–21.20 |
| DTPA-extractable Zn (mg $kg^{-1}$) | 0.79 | 0.48 | 0.38–1.42 |
| DTPA-extractable Cu (mg $kg^{-1}$) | 0.98 | 0.76 | 0.26–3.22 |

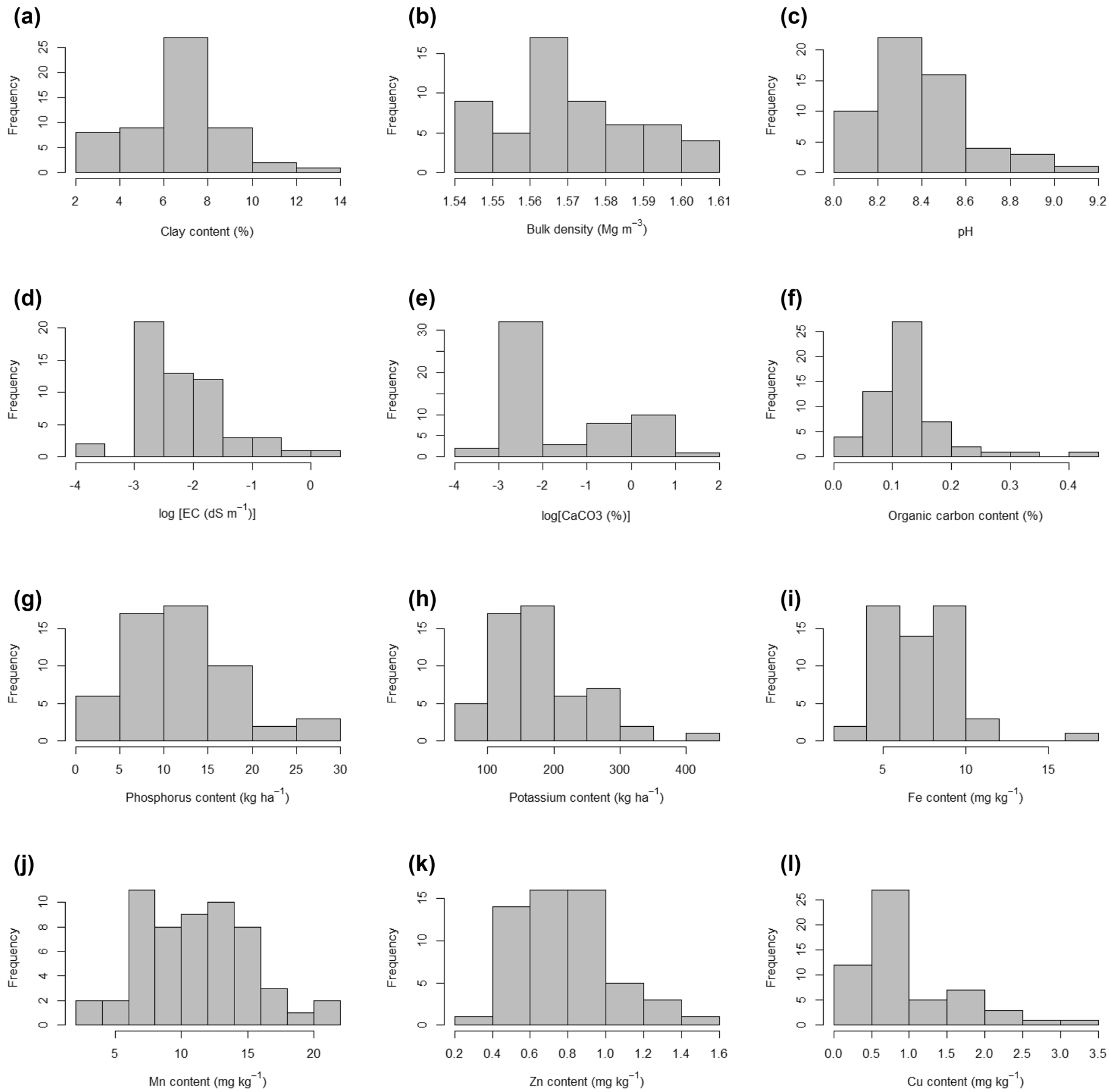
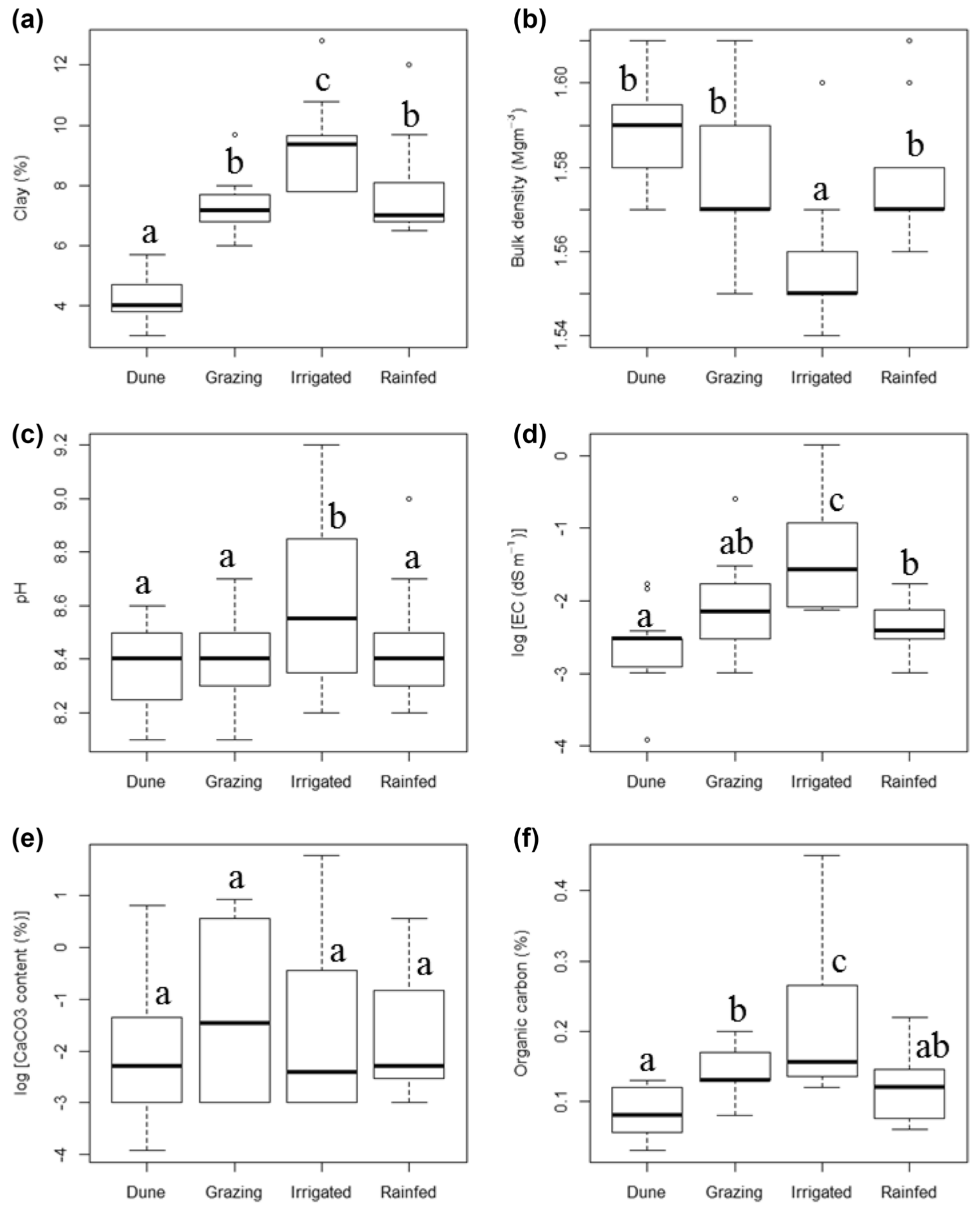



**Fig. 2** Histogram plot of soil properties in Jhunjhunu district; **a** clay content (%), **b** bulk density (Mg m$^{-3}$), **c** pH, **d** electrical conductivity (dS m$^{-1}$), **e** $CaCO_3$ content (%), **f** organic carbon content (%), **g** P content (kg ha$^{-1}$), **h** K content kg ha$^{-1}$), **i** Fe content (mg kg$^{-1}$), **j** Mn content (mg kg$^{-1}$), **k** Zn content (mg kg$^{-1}$), **l** Cu content (mg kg$^{-1}$)

croplands might be due to continuous addition of phosphatic fertilizers and organic manures because of intensive cultivation during both *rabi* and *kharif* seasons. Available K content was on average 177.3 kg ha$^{-1}$ with a range between 84 kg ha$^{-1}$ and 442 kg ha$^{-1}$, and it was statistically similar across land use systems (Fig. 4b). Soils were found adequate in available Fe, Mn, Cu and Zn and were almost similar in their contents across land use systems. DTPA-extractable Fe content ranged from 3.8 to 16.5 mg kg$^{-1}$. DTPA-extractable Mn content ranged between 3.6 and 21.2 mg kg$^{-1}$ with a mean value of 11.17mg kg$^{-1}$. Zinc content ranged from 0.38 to 1.42 mg kg$^{-1}$, whereas Cu content varied from 0.26 to 3.22 mg kg$^{-1}$.

Fig. 3 Soil properties across different land use system in Jhunjhunu district; **a** clay content (%), **b** bulk density ($Mg\ m^{-3}$), **c** pH, **d** electrical conductivity ($dS\ m^{-1}$), **e** $CaCO_3$ content (%), **f** organic carbon content (%); letters on top of each box indicate statistical similarity (boxes with similar letters) or dissimilarity (boxes with dissimilar letters) between land use systems ($p < 0.05$)




## Correlation Among Soil Properties

Correlation among soil properties in the study area is presented in Table 3. Significant correlation has been observed between most of the soil properties. Specifically, clay content and BD are highly correlated ($r = -0.68^{**}$), whereas OC content is highly correlated with clay ($r = 0.69^{**}$) and BD ($r = -0.67^{**}$). Increase in OC and clay content of soil increases the micropores in soil matrix and thus decreases the bulk density. Soil nutrient contents, both macronutrients (P and K content) and micronutrients (Fe, Cu, Mn) are significantly correlated with OC content and clay content, which is mainly due to increase in available exchange sites for nutrient retention and increase in formation of clay–humus complexes. Overall, it has been observed that soil physical and chemical properties are interrelated with each other. Therefore, for realistic assessments of soil resources as influenced by land use, it was necessary to combine all these interrelated soil properties into a few major soil factors instead of evaluating the land use impact on each soil property individually.

## Principal Components of Soil Properties

Principal component analysis was carried out with an aim to group several measured soil properties to a few soil components. Eigenvalues indicate the percentage of variance explained by a principal component. It has been found that 5 principal components (PCs) derived from 12 measured soil properties explained about 80% variation in the

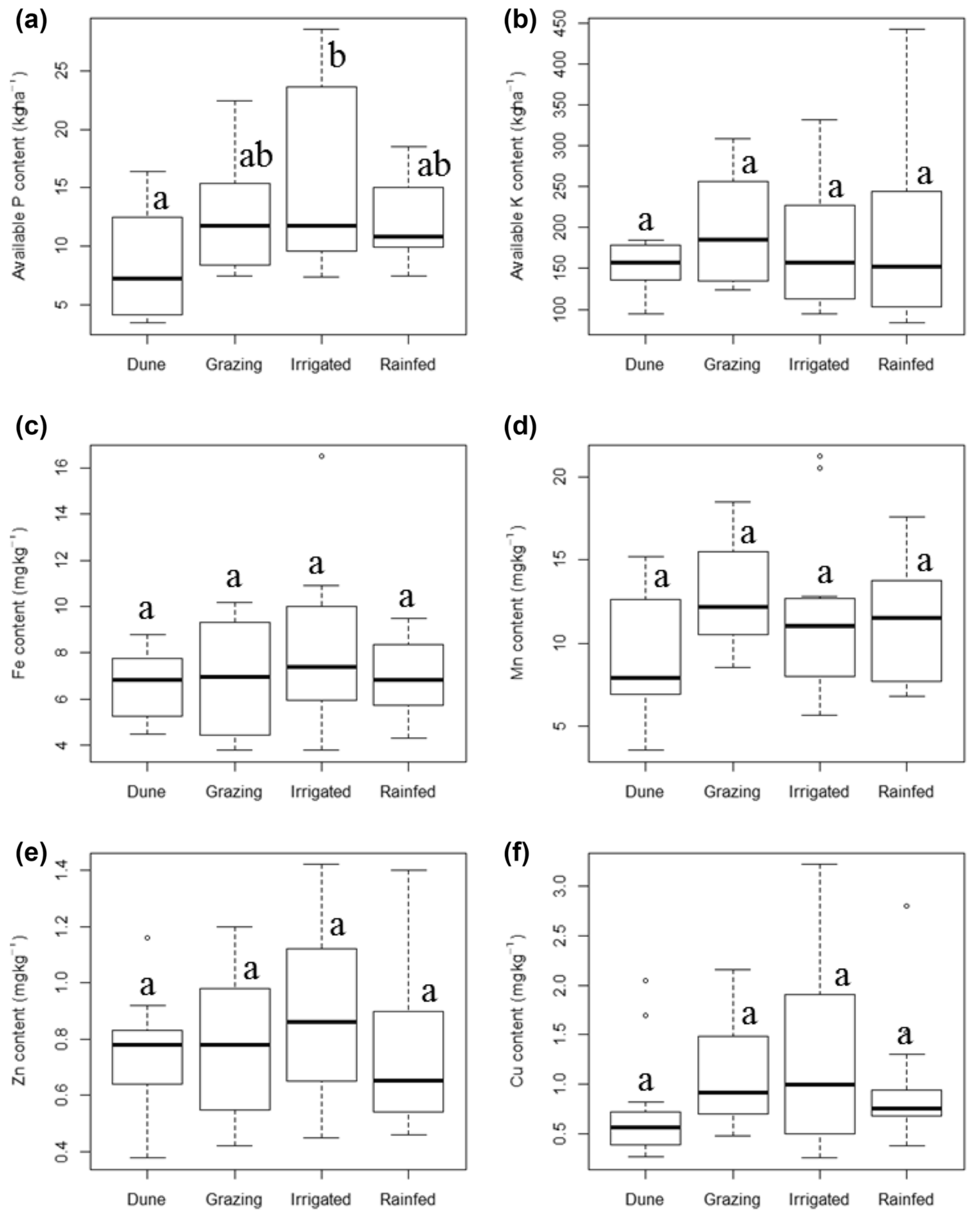



**Fig. 4** Soil properties across different land use system in Jhunjhunu district; **a** available P content (kg ha$^{-1}$), **b** available K content (kg ha$^{-1}$), **c** Fe content (mg kg$^{-1}$), **d** Mn content (mg kg$^{-1}$), **e** Zn content (mg kg$^{-1}$), **f** Cu content (mg kg$^{-1}$); letters on top of each box indicate statistical similarity (boxes with similar letters) or dissimilarity (boxes with dissimilar letters) between land use systems ($p < 0.05$)

dataset. These major PCs were expected to explain influence of land use system on soil resources. Eigenvectors obtained from principal component analysis are plotted as scatter diagram in a circle of unit radius (Fig. 5). It shows how strong the influence of soil properties on derived orthogonal components is; nearer they plot to the circumference stronger they are in the component, whereas closer to the center of the circle weaker is the influence. Moreover, their proximity to one another shows how related the original variables are to one another. From the figure, it has been observed that first component divides the soil properties in two groups; only bulk density is located on left half of the circle, whereas rest properties are on the right-hand side. This indicates that soil samples having higher bulk density lead to lower value of PC1, whereas higher value of the rest of soil properties increases the PC1. Similarly, the second component discriminates the soil properties in two distinct groups; one having pH and EC, whereas the second group consists of four micronutrients (Fe, Mn, Zn and Cu) and $CaCO_3$ content. It has also been observed that clay, OC, P and K lie in one cluster which indicates that they are strongly related to each other. Similar is the case for cluster of Fe, Mn, Zn, Cu and $CaCO_3$ content.

Loading factors of different soil properties to major PCs are presented in Table 4. Organic carbon, clay content and bulk density contributed largely to PC1 as indicated by their higher loading factor, whereas these factors were positive for OC and clay content and negative for bulk density. It indicates that with increase in either OC and clay

**Table 2** Chemical characteristics of water used for irrigation

| Site no. | pH | EC | Cations (me $L^{-1}$) | | | | Anions (me $L^{-1}$) | | | RSC (me $L^{-1}$) | SAR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | K | $CO_3^{-2}$ | $HCO_3^{-1}$ | Cl | | |
| 1 | 8.90 | 1.20 | 0.20 | 1.68 | 12.20 | 0.04 | 2.20 | 8.10 | 3.05 | 8.42 | 12.60 |
| 2 | 8.61 | 1.20 | 0.36 | 0.76 | 11.70 | 0.03 | 1.20 | 4.80 | 5.45 | 4.88 | 15.64 |
| 3 | 8.50 | 1.10 | 0.56 | 1.02 | 10.90 | 0.05 | 0.60 | 4.65 | 6.05 | 3.67 | 12.38 |
| 4 | 8.54 | 2.70 | 1.12 | 3.66 | 23.30 | 0.05 | 1.20 | 5.50 | 18.10 | 1.92 | 15.08 |
| 5 | 9.02 | 2.02 | 0.54 | 1.68 | 24.60 | 0.04 | 2.20 | 14.08 | 6.70 | 14.06 | 23.36 |
| 6 | 9.03 | 2.60 | 0.14 | 2.54 | 26.90 | 0.08 | 4.20 | 11.60 | 11.42 | 13.12 | 23.24 |
| 7 | 9.10 | 2.70 | 0.37 | 1.63 | 29.10 | 0.04 | 4.40 | 12.40 | 8.65 | 14.80 | 29.10 |
| 8 | 8.70 | 1.86 | 0.56 | 2.18 | 16.90 | 0.04 | 1.00 | 7.35 | 6.35 | 5.61 | 14.44 |
| 9 | 9.02 | 3.05 | 0.20 | 2.84 | 30.45 | 0.04 | 3.00 | 12.00 | 9.80 | 11.96 | 24.75 |
| 10 | 8.84 | 2.45 | 0.37 | 2.87 | 23.90 | 0.04 | 2.40 | 8.00 | 12.10 | 7.16 | 18.81 |
| 11 | 9.01 | 4.20 | 0.22 | 5.02 | 39.15 | 0.06 | 4.20 | 9.40 | 18.72 | 8.36 | 24.19 |
| 12 | 8.34 | 1.90 | 0.60 | 2.57 | 20.40 | 0.03 | 1.20 | 10.30 | 8.20 | 8.33 | 16.32 |
| 13 | 7.89 | 2.60 | 1.32 | 6.48 | 20.8 | 0.10 | 0.30 | 8.10 | 13.80 | 0.60 | 10.55 |
| 14 | 8.07 | 0.52 | 0.80 | 2.69 | 13.90 | 0.10 | 0.40 | 3.70 | 6.50 | 0.61 | 10.53 |
| 15 | 8.30 | 1.70 | 0.48 | 1.36 | 17.30 | 0.05 | 1.20 | 5.30 | 9.80 | 4.66 | 18.21 |

**Table 3** Correlation coefficients among soil properties in Jhunjhunu district of western Rajasthan

| Soil properties[a] | Clay | BD | pH | log [EC] | log [$CaCO_3$] | OC | P | K | Fe | Mn | Zn | Cu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clay | 1 | | | | | | | | | | | |
| BD | − 0.68** | 1 | | | | | | | | | | |
| pH | 0.21 | − 0.23 | 1 | | | | | | | | | |
| log [EC] | 0.39** | − 0.40** | 0.32* | 1 | | | | | | | | |
| log [$CaCO_3$] | 0.07 | − 0.14 | 0.05 | − 0.07 | 1 | | | | | | | |
| OC | 0.69** | − 0.67** | 0.30* | 0.34** | 0.18 | 1 | | | | | | |
| P | 0.61** | − 0.58** | 0.25 | 0.11 | − 0.05 | 0.80** | 1 | | | | | |
| K | 0.40** | − 0.39** | 0.17 | − 0.03 | 0.15 | 0.60** | 0.48** | 1 | | | | |
| Fe | 0.43** | − 0.37** | 0.00 | − 0.05 | 0.15 | 0.44** | 0.54** | 0.26 | 1 | | | |
| Mn | 0.40** | − 0.48** | − 0.14 | 0.06 | 0.11 | 0.35** | 0.31* | 0.39** | 0.36** | 1 | | |
| Zn | 0.12 | − 0.29* | 0.05 | 0.20 | 0.01 | 0.05 | 0.11 | − 0.15 | 0.20 | 0.07 | 1 | |
| Cu | 0.30* | − 0.30* | − 0.11 | 0.18 | 0.11 | 0.46** | 0.41** | 0.12 | 0.35** | 0.29* | 0.43** | 1 |

[a]BD, bulk density (Mg $m^{-3}$); EC, electrical conductivity (dS $m^{-1}$); $CaCO_3$, calcium carbonate content (%); OC, organic carbon content (%); P, available P content (kg $ha^{-1}$); K, available K content (kg $ha^{-1}$); Fe, Mn, Zn and Cu = DTPA-extractable Fe, Mn, Zn and Cu content (mg $kg^{-1}$)

*Significant at $p < 0.05$; **Significant at $p < 0.01$

content, its PC1 score will also increase, whereas with an increase in bulk density its PC1 score will decrease. The major relations of soil properties with PC scores are presented in Fig. 6. Based on the loading factors of different soil properties, PC1 may be termed as a clay–carbon factor as indicated by higher absolute values for clay content, carbon content and bulk density. This soil factor may be computed from corresponding loading factors of soil properties to PC1 as mentioned in Table 4. Similarly, PC2 may be termed as a soil salinity factor as the loading factor of pH and EC was higher than other soil properties. Loading factor of both pH and EC was negative, which indicates that with an increase in these properties, values of salinity factor will decrease and vice versa, which is plotted in Fig. 6. Salinity factor may be computed from corresponding loading factors of soil properties to PC2.

Both the clay–carbon factor (PC1) and salinity factor (PC2) of samples with different land use category have been presented in a biplot (Fig. 7). Each sample in this plot is represented by an alphanumeric code, in which first

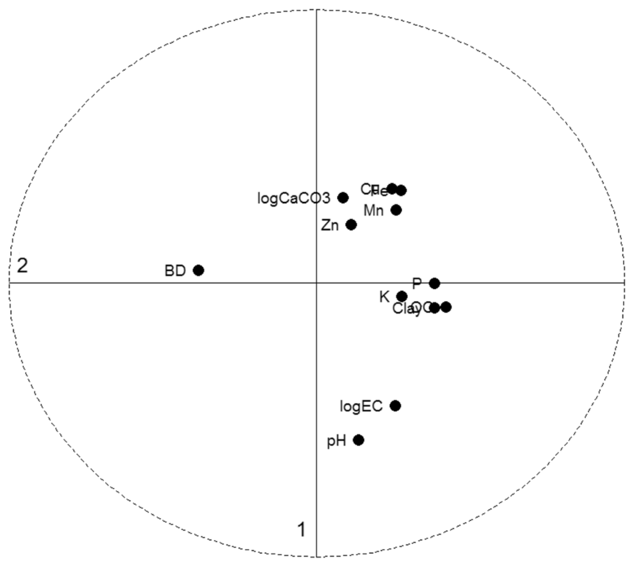



**Fig. 5** Scatter plot of the soil properties as their correlation coefficients (eigenvectors) between them and the first two principal components in the unit circle

character indicates land use category (D = Dunes, G = Grazing, I = Irrigated croplands, R = Rainfed croplands). Most of samples from irrigated cropland category lie at bottom right quadrant indicating high values of clay–carbon factor and low value of salinity factor, whereas samples from dunes, rainfed cropland and grazing land are mostly concentrated in top left and bottom left quadrates indicating low values of clay–carbon factor. Therefore, these two factors clearly showed the difference in soil resources between irrigated croplands and other land use categories in the region. Direction and magnitude of influence of each soil property to these soil factors are also indicated in Fig. 5. Length of the vector indicates the magnitude of loading factor, whereas direction indicates positive or negative influence of each soil property on these soil factors. It has been found that PC1 or clay–carbon factor is parallel to x-axis and BD has the just opposite influence of OC, clay and other soil properties. Salinity factor PC2 has been found perpendicular to x-axis, and pH and EC have the downward or negative influence on this factor.

## Land Use Versus Soil Factors

Clay–carbon factor and salinity factor derived through principal component analysis of twelve soil parameters are presented in box plots under four land use categories (Fig. 8). Clay–carbon factor has been found highest and positive for irrigated cropland, whereas lowest and negative for sand dune category (Fig. 8a). For grazing land and rainfed cropland, this factor is almost similar and very close to zero. It indicates that cultivation in desert landscape through irrigation has enriched soil carbon and clay content and overall improved the soil physicochemical environment for crop growth. However, if we see the soil salinity factor (Fig. 8b), it is lowest and negative for irrigated cropland, whereas almost similar and close to zero for rainfed cropland, grazing land and dunes. It indicates that soil salinity with higher pH and EC is a problem in irrigated cropland. Overall, it has been noted from the above findings that crop cultivation in sandy plains of the region through irrigation improved the soil physiochemical environment, however, increased the problem of soil salinity. If we consider sand dune as the reference land use category, cultivation either rainfed or irrigated or even the rangeland management for grazing purpose have been found to improve soil physiochemical environment.

**Table 4** Factor loadings of major principal components

| Soil properties | PC1[a] | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Clay | **0.385** | − 0.091 | − 0.011 | − 0.028 | 0.138 |
| BD | **− 0.383** | 0.046 | − 0.078 | − 0.042 | − 0.259 |
| pH | 0.136 | **− 0.575** | 0.087 | 0.348 | − 0.232 |
| Log[EC] | 0.256 | **− 0.448** | 0.276 | − 0.066 | 0.363 |
| log[$CaCO_3$] | 0.085 | 0.313 | − 0.232 | **0.832** | 0.280 |
| OC | **0.421** | − 0.087 | − 0.108 | 0.077 | − 0.111 |
| P | 0.382 | − 0.003 | − 0.076 | − 0.085 | **− 0.435** |
| K | 0.277 | − 0.048 | − 0.472 | − 0.046 | − 0.038 |
| Fe | 0.274 | 0.339 | − 0.034 | − 0.045 | − 0.446 |
| Mn | 0.258 | 0.268 | − 0.153 | − 0.372 | **0.493** |
| Zn | 0.112 | 0.213 | **0.676** | 0.152 | − 0.017 |
| Cu | 0.245 | 0.343 | 0.366 | − 0.011 | − 0.069 |

[a]Bolded values indicates higher absolute loadings

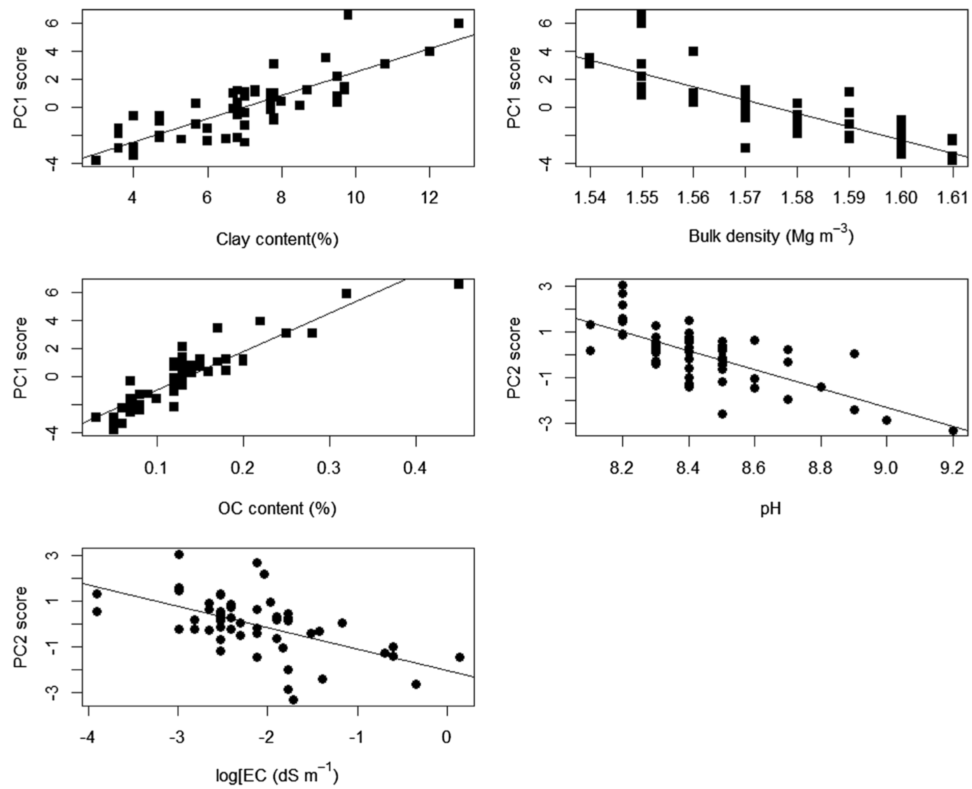



**Fig. 6** Major principal components derived from principal component analysis and their relation with individual soil properties

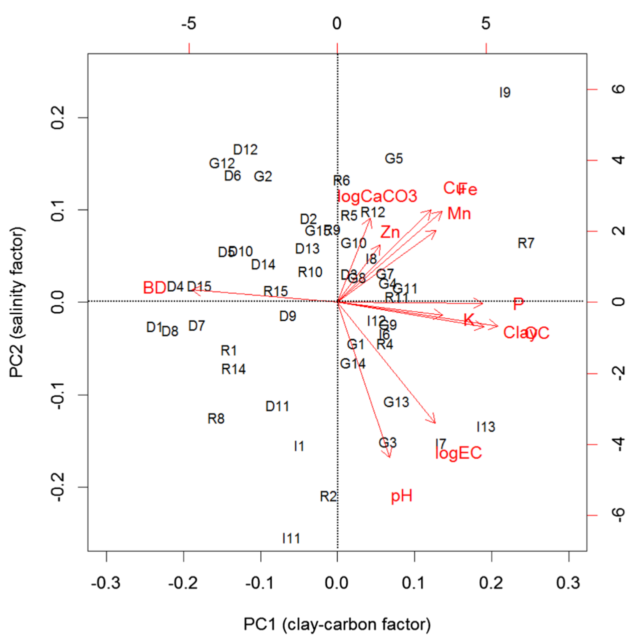



**Fig. 7** Biplot of two major principal components of soil properties in Jhunjhunu district; first letter of symbols for each data point represents the land use system (D = Dunes; G = Grazing land, I = Irrigated cropland, R = Rainfed cropland)

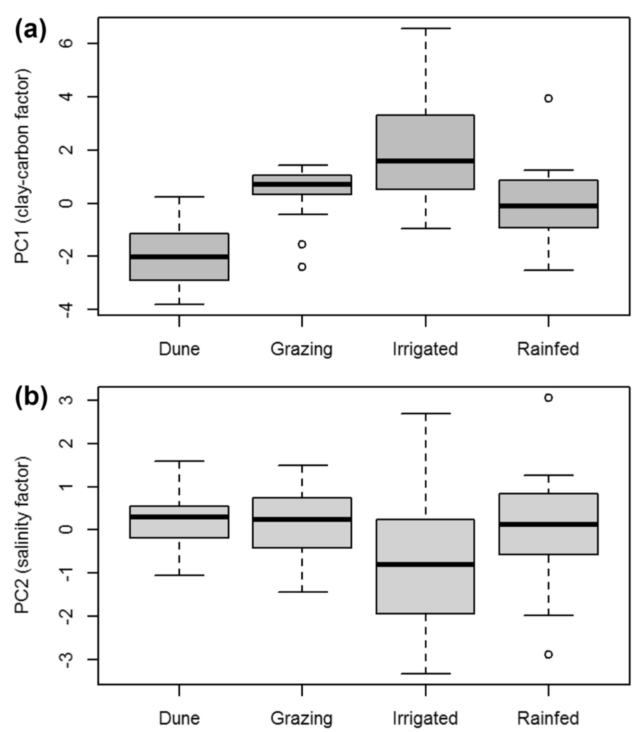



**Fig. 8** Major principal components under four land use systems in Jhunjhunu district

Simultaneously, soil salinity factor under rainfed cropland and grazing land is almost similar with sand dune category, which indicates that soil salinity is not influenced through rainfed cultivation or rangeland management.

## Discussion

### Soil Physicochemical Properties Versus Land Use

Soil pH was found higher under irrigated croplands than rest land use categories. Quality of irrigation water used for growing crops in irrigated croplands might have raised the soil pH significantly. Chemical analysis of ground water revealed high Na content in it along with predominance of carbonates and bicarbonates salts in comparison with Ca and Mg and the presence of Na-rich aquifer may be the possible reason of higher Na content in ground water. Continuous irrigation with such waters leads to excessive Na content in soil solution, which ultimately resulted in high soil pH [13]. On the basis of limit suggested by Muhr et al. [21], most of the samples were found normal in salinity (EC $< 1.0$ dS $m^{-1}$). Higher contents of fine soil particles (clay and silt) in the irrigated croplands than the rest of the land uses may be due to continuous irrigation, which helps to keep the soil surface under crop cover for about 9–10 months in a year and thus protects topsoil from erosion by wind. Increased crop cover also helps to entrap fine particles blown away from the nearby barren or uncultivated field through wind erosion. It has also been observed that in comparison with rainfed croplands or sand dunes, soil under grazing land had 6–8% higher clay + silt content (Table 1). The improvement in silt and clay content beneath shrub canopies is reflected by lower degree of wind erosion surrounding shrub canopies. Higher clay + silt content in grazing lands might also be due to entrapment of blown soil particles by shrub canopies and also through stem flow and through fall of rain water which carries the deposited fine particles from canopy surface to ground surface [32]. Furthermore, the increase in silt + clay and accumulation of litter were favorable for soil structure improvement, which could led to decrease in BD and increase in water holding capacity (WHC) of soil [30]. In contrary to this, poor vegetation cover in rainfed croplands might have increased the problem of wind erosion, which further resulted in the lowest clay and silt content in this land use category. Furthermore, irrigation practices enhanced the cropping intensity and thus had a greater chance of incorporating more amounts of crop residues into the soils than other land use categories. High cropping intensity influenced the pedogenic processes and resulted in fine to medium, moderate sub-angular blocky soil structure in irrigated lands as compared to single grained loamy textured soils without irrigation [5, 9].

Higher amount of OC in irrigated croplands might be due to addition of crop residues in the soil, which was also reported by Lal et al. [17] and Denet et al. [4] for semiarid situations. Higher OC content in irrigated lands might also be due to reduction in summer fallowing, which generally enhances SOC depletions in arid and semiarid tropics [7] and has also been reported for Thar Desert of India [27]. A similar observation on increased OC in irrigated croplands due to reduced summer fallowing in semiarid region of Argentina was also reported by Miglierina et al. [20]. High soil temperature and poor vegetative cover of soils in sand dunes and rainfed lands might have increased the rate of oxidation of soil organic matter resulting in the reduction in OC contents in these land use categories [27, 29].

The increase in available phosphorus under irrigated croplands could be due to carry-over effect of continuous application of phosphate fertilizers [15, 28]. These soils have been cultivated during both *rabi* and *kharif* seasons with support of irrigation facilities, and therefore, it receives higher amount of fertilizers (urea and DAP) and organic manures. Continuous irrigation in these soils also improved the soil biological activity, which have contributed to higher available phosphorus content [2, 17]. Available phosphorus content varies widely in arid soils and the average content is $< 20$ kg $P_2O_5$ $ha^{-1}$, but the contents could be higher in cultivated soils [10]. Higher content of available phosphorus in intensively cultivated lands was also reported by Kenny et al. [12].

Across the land use systems, available K was highest in grazing lands and lowest in sand dunes. Lower content of soil potassium in irrigated lands than grazing lands might be due to continuous cropping without replenishment of depleted potassium reserve in soil. Depletion of available K was also reported from intensively cultivated lands in the Thar Desert of India [27] as well as in Frazer valley of Canada [12]. Higher available K content in grazing lands might be due to the higher root activities of existing vegetation and also through addition of excreta by grazing animals [14].

The DTPA-extractable values for Fe, Mn, Zn and Cu were significantly higher in irrigated crop lands and grazing lands than in sand dunes, and that might be due to the addition of several micronutrients through litter fall and through the application of inorganic sources. The results were in close agreement with those reported by and Kumar et al. [14].

### Soil Factors as Indicators of Land Use Impact

Overall, we observed the improvement in soil physical and chemical properties in irrigated croplands. For example, clay content, OC content and available P were higher in irrigated crop lands than other land use systems. Contrary to this, soil pH and EC have been observed higher in irrigated croplands than rest land uses, which is considered as the negative impact of irrigation. We tried to combine several measured soil physical and chemical properties into few factors by which we can judge the impact of land use systems on soil physicochemical environment. Principal component analysis helped us to combine several soil physicochemical properties into two major soil factors, clay–carbon factor and salinity factor, which clearly differentiated the impact of land use system. Higher value of clay–carbon factor and lower value of salinity factor are desirable for better soil productivity. We observed higher value of clay–carbon factor for irrigated croplands; however, salinity factor was also observed slightly higher in these croplands than rest land use categories. Based on these findings, we may categorize these two factors as follows: clay–carbon factor as very good (4 to 2), good (2 to 0), poor (0 to − 2), very poor (− 2 to − 4) and salinity factor as very good (− 1 to − 2), good (0 to − 1), poor (1 to 0) and very poor (2 to 1). These two factors may be used for any future assessment of land use impact on soil resources in Indian Thar Desert as well as in other arid and semiarid parts of the world.

## Conclusions

Influence of land use changes on soil resources was evaluated in Jhunjhunu district of western Rajasthan, India. The present study was carried out as a result of the observations noted from a previous study during the last 20–30 years on significant changes in the land use pattern in the study area. A large portion of cultivated area under rainfed system has been shifted to irrigated system. Therefore, it became essential to assess the soil productivity changes resulted from the forcible land use changes occurred in the region. Comparative analysis of two soil factors across land use systems has revealed highest and positive values of clay–carbon factor under *rabi* croplands or irrigated agriculture system, while lowest and negative values under dunes or sandy wastelands. However, the salinity factor has been found lowest and negative in *rabi* croplands, while for other land use systems, it is almost similar and very close to zero. Therefore, it is concluded that shift of land use system to irrigated agriculture has improved the soil resources, but has slightly increased soil salinity. For sustainable management of lands under irrigated system, it is suggested to implement suitable preventive measures to control or reduce the salinity problem in hot arid regions, e.g., keeping fallow in alternate years during rainy seasons to allow the salts to leach down the soil profile, growing of salt-tolerant crops and varieties, cultivation of low water requiring crops.

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