Characterization of Salt-affected Soils and Water Resources in Sub-humid Southern Plains of Rajasthan

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Thesis

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In Partial Fulfillment of the Requirement for

The Degree of

Doctor of Philosophy in Agriculture

(*Soil Science*)

By
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2005

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This is to certify that the thesis entitled "**Characterization of Salt-affected Soils and Water Resources in Sub-humid Southern Plains of Rajasthan",** submitted for the degree of **Doctor of Philosophy in Agriculture** in the subject of **Soil Science,** embodies bonafide research work carried out by **Mr. Nav Raten Panwar** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of this thesis was also approved by the advisory committee on **July 26, 2005.**

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CONTENTS

1. Introduction

Accumulation of excess salt in the root zone resulting in a partial or complete loss of productivity is a worldwide phenomenon. The problem of soil salinity is most widespread in the arid and semi-arid region but salt-affected soils also occur extensively in sub-humid and humid climates. Irrigation is considered to be an essential input to increase agricultural production for satisfying the food requirement of mushrooming population. However, the most serious problem of salinity through secondary salinization is being faced in the canal irrigated/command regions of the world.

The world's irrigated areas are currently estimated to stand at 260-270 m ha (Hooja *et al.,* 2000). At global level 76.6 m ha of land is engraved with secondary salinization, of which 70 per cent is in Asia and 20 per cent in Africa. Lack of adequate drainage network in an irrigated command disturbed the favourable water balance and caused gradual rise of water table. It is a burning issue in canal command areas looking to an alarming increasing rate of rising water table. In IGNP (Indira Gandhi Nahar Pariyojna) Command Area, the potential sensitive zone to water logging has raised to 50 per cent from 9 per cent in last two decades (1981 to 2000).

Study of the maps published by the National Bureau of Soil Survey and Land Use Planning and their accompanying reports place the area affected by salinity and sodicity in the country at 21.62 m ha. If the area affected by slight salinity/slight sodicity in Rajasthan, Maharashtra, Andhra Pradesh, Madhya Pradesh and Gujarat states aggregating to 7.0 m ha is subtracted from the grand total of salt-affected area i.e., 21.62 m ha then actual area comes out to be 14.62 m ha warranting attention for proper management shall exist in the country. Out of 14.62 m ha of salt-affected soils in India 7.74 m ha is saline and 6.88 m ha is sodic in nature (Bhargava and Kumar, 2004).

Both sodic and saline soils are usually classed together as salt-affected soils. These soils contain sufficient levels of soluble salts and/or exchangeable sodium to interfere with growth of most crop plants. The adverse effect may be through rise in osmotic pressure as a consequence of the increased level of soluble salts, nutritional imbalance and/or toxicity caused by specific ions. In sodic soils, poor growth is often due to associated adverse physical properties such as surface crusting, reduced permeability to water and air and increased mechanical resistance to root penetration (Loveday and Bridge, 1983). The impact of soil salinity and/or sodicity on soil environment is a most serious land degradation issue.

Soil degradation through salinization and sodification is seriously affecting the productivity of large stretches of productive lands. Salt affected soils are distributed in almost all the agroecological regions. The major causes for the development of salt-affected soils in Rajasthan are, topography, area adjoining to salt lake, Ghaggar flood plains, sources of irrigation and cultivation with saline water (Moghe and Mathur, 1984).

The revenue records available for salt-affected lands (including unutilized barren land) reveals that about 25 per cent of gross cultivated area are salt-affected in district Chittorgarh (Anonymous, 2002). Looking to the magnitude of the problem, district Chittorgarh was chosen for proposed investigation. The principal causes leading to the accumulation of salts in the area under study may be ascribed to:

1. Salts have been formed by the atmospheric decomposition of granite and gneissic rocks of the Aravalli Hill ranges whose component felspathic and allied minerals on chemical weathering gives the sodium salts (Sarin, 1952).

2. The rising water table in area adjoining to many irrigation tanks of Chittorgarh district has led to the formation of saline alkali soils under tank irrigation. Though the water quality of the tanks in most of the cases are good but construction of kuccha bund above the ground results in lateral movement of water in the soil of the command area. Simultaneously, a calcium carbonate layer in substratum of the soil does not permit downward entry of water, leading to upward movement of salts and consequently their accumulation in the root zone.

3. Because of low rainfall in the area, the ground waters are not fully recharged for years together resulting in an increase in the level of salinity every year wherever the evaporation due to high temperature, exceeds total precipitation. Use of poor quality underground water for irrigation results into accumulation of salts in the soil.

Mehta (1962), Seth (1967) and Mathur *et al.* (1968) classified soils of Rajasthan based on a broad reconnaissance survey. Hooja *et al*. (1995), Kalra and Joshi (1996), Mathur *et al.* (1996) and Mondal and Sharma (1997) have characterized the salt-affected soils in selected areas of the Rajasthan state. As such the information dealing with different kind of salt-affected soils and their relationship with soil properties, which have significance in reclamation and management is in general, are scanty, particularly in context to the Southern Plains of Rajasthan. Sharma and Totawat (2000) while working on soils of Bhilwara district, sub-humid southern plain of Rajasthan reported that a total area 1,29,501 ha is salt-affected forming 12.43 per cent of the total physiographic land. An understanding of the nature and distribution of salt-affected soils and their mode of formation are the basic requirement for formulation of long term programmes of management, reclamation and preventing them from reverting back, as well as to maintain the sustainability of system in mitigating the challenges of ever growing population.

Keeping in view the present investigation entitled, "Characterization of salt-affected soils and water resources of Sub-humid Southern Plains of Rajasthan" is aimed at**:**

1. To identify the nature and extent of the salt-affected soil in district Chittorgarh of zone IVa,
2. to categorise the salt-affected soils of district Chittorgarh and suggest the management practices to be followed and develop suitable land use plan for such areas,
3. to identify underground brackish water in area under study (district Chittorgarh), and
4. to characterize and classify the irrigation water quality for their efficient use.

2. REVIEW OF LITERATURE

Nearly as much as 14.62 million hectare of land in the arid and semi-arid regions of Indian subcontinent is reported to have affected by some degree of salinity and sodicity or both (Bhargava and Kumar, 2004), limiting agricultural production. The soil salinity/sodicity is becoming a major problem in irrigated agriculture. The dynamics of salt-affected soils and soil water management techniques to mitigate adverse effects of salts are well documented. However, the problem of salt accumulation, though, consistent but their characterization and classification will be elusive in accurate mapping. Attempts have been made by several workers (Sharma and Bhargava, 1988; Rao *et al.*, 1991; Diwedi, 1992; Verma *et al.*, 1994; Verma *et al.*, 1995 and Sharma and Totawat, 2000) to delineate the spatial extent of salt-affected soils. Through scanning of literature, the work done in India and abroad related to soil salinity/sodicity, characterization, classification and land use planning as well as quality of irrigation water is reviewed under this chapter. This will elucidate the situation clearly to the investigation under study.

A brief account of the work appeared in the literature on various aspects of the present investigation is presented in the following subheads**:**

2.1 Characterization of salt-affected soils

- 2.1.1 Morphological characteristics
- 2.1.2 Physical characteristics
- 2.1.3 Chemical characteristics

2.2 Soil classification

- 2.2.1 Russian classification
- 2.2.2 Soil taxonomy
- 2.2.3 Classification of salt-affected soils

2.3 Land use planning

2.4 Quality of well waters and their suitability for irrigation

2.5 Management alternatives

2.1 CHARACTERIZATION OF SALT-AFFECTED SOILS

2.1.1 Morphological characteristics

Soil morphological characteristics like soil colour, texture and structure depends upon various soil forming factors and processes. There are five soil forming factors (parent material, relief, time, climate and biosphere) which are interrelated and complement to one another, likewise, soil forming processes involving addition, leaching, redistribution and reorganization etc. which lead to the development of a soil with distinct morphological features. Among different morphological features of soils, their colour is an important macro-morphological property and is the resultant of various factors.

(A) Colour: The black or dark colour of regur soils was due to clay, organic matter and calcium status of these soils (Joshi, 1950 and Agarwal *et al.,* 1956). Dudal and Bramo (1965) attributed the dark colour to the presence of iron sulphide and manganese oxide in addition to clay-organic matter complex. Jha and Sharma (1989) reported that the gray colour of the soils was due to the presence of high amount of calcium carbonate. Grayish brown to dark grayish brown and dark yellowish brown colour of the soil matrix of salt-affected soils in Etah district was reported by Verma *et al.* (1995). The colour of the salt-affected soils of Indira Gandhi Nahar Pariyojana Command Area, Rajasthan varies from yellowish brown to pale brown, while the darker colour in subsurface horizons due to the presence of some Fe and Mn mottles have been reported by Mondal and Sharma (1997). Similar results were also reported by Bhaskar and Nagaraju (1998) in Chitravathi river basin of Andhra Pradesh. Sharma and Totawat (2000) while working on soils of Bhilwara district of Sub-humid Southern Plain of Rajasthan have reported that colour of salt-affected soils varied from very dark grayish brown (10 YR 3/2 M) to very pale brown (10 YR 7/4 M). Nayak *et al.* (2000) while working on some salt-affected soils of Bhal Region of Gujarat have reported brown to dark brown colour in surface and reddish yellow colour in subsurface horizons. Challa *et al.* (2000) reported that Khondwad and Kadambhe soils are dark grayish brown while Amalnar and Valpi soils are dark yellowish brown in colour in Ahmednagar and Akola district of Maharashtra plateau. Durgude *et al.* (2004) while working on sodic soils of district Rahuri, Maharashtra have reported the colour of soils ranged from very dark gray (10 YR 3/1) to very pale brown (10 YR 7/2). Sharma *et al.* (2004) while studying on some salt-affected soils of district Bhilwara, Rajasthan have reported yellowish brown (10YR 4/4) to light yellowish brown (10YR 6/4) and very dark brown (10YR 3/3) colour of the salt-affected soils of the region. Kharche *et al.* (2004) reported that colour of sodic vertisols of Mula Command Area of Maharashtra are varied from dark grayish brown and very dark grayish brown in the surface horizons to dark gray and dark grayish brown in the subsurface.

(B) Soil structure: While working with soils of Rajasthan, Saxena and Singh (1982) observed a variation in the soil structure from granular to sub-angular blocky in the profile layers of medium black soils, but in non calcic brown soils (saline phase), it is single grained owing to the presence of higher content of coarser fractions. Sharma and Dev (1985) studied the genesis of soils on different geomorphic surfaces in a river in plains of Punjab and observed weak to moderate sub-angular blocky structure in the profiles from upper terrace channel, suggesting the formation of an altered B (cambic) horizon. However, the soils in surface horizon of the channel have massive structure and contained upto 50 per cent clay, which was attributed partly to the settling of finer particles received alongwith runoff water from surrounding areas during rainy seasons. Qureshi *et al.* (1996) while studying saline and sodic soils in Bharatpur district, recorded prismatic to columnar and sub-angular blocky structure in the subsurface horizons, though, no pedality was witnessed in few horizons. Further, Bhaskar and Nagaraju (1998) also reported angular blocky to prismatic structure in subsurface layers.

Sharma *et al.* (2004) while studying the salt-affected soils of district Bhilwara, Rajasthan, observed sub-angular blocky structure in the surface horizons, however, in substratum of slightly and moderately saline soil layer, structure becomes massive indicating lack of development or destruction of soil structure due to prevailing moist conditions in the soils.

Challa *et al.* (2000) while working on salt-affected vertisols in semi-arid ecosystem in Ahmednagar and Akola district of Maharashtra recorded structure ranged from medium, moderate sub-angular blocky to coarse, strong sub-angular to angular blocky through depth in all the profiles. Nayak *et al.* (2000) while studying on some salt-affected soils of Bhal region of Gujarat recorded sub-angular blocky in all horizons (P_2 & P_3) and angular blocky structure in subsurface horizons of pedon 1 and pedon 4. Garg *et al.* (2000) was also of opinion that structure in sodic soils of the Gangatic alluvial plains of Bathra, Lucknow was sub-angular blocky to angular blocky. However, Durgude *et al.* (2004) reported columnar to prismatic structure in sodic soils of Rahuri district, Maharashtra.

(C) Texture: Texturally the salt-affected soils are mainly sandy loam to clayey. The clay content of different areas indicates that in general, there is invariably a zone of maximum accumulation of clay in the lower horizon. Illuviation of clay is a characteristic of these soils (Gawande *et al.*, 1980; Pathak and Patel, 1980; Vinayak *et al.*, 1981; Sahu and Dash, 1993; Balpande *et al.*, 1996; Challa *et al.*, 2000). Contrary to this Kumar *et al.* (1994) reported silty loam followed by clay loam soil texture in different geomorphic location and climate in the Satluj–Yamuna divide sodic soils. However, Verma *et al.* (1995) reported loamy sand to sandy loam with slight change in structure and consistency in droughty soils of Etah district of U.P.

The soils were sandy loam to clay loam and the clay content was more in the lower horizons in all the profiles of Matunda regions of Chambal Command Area (Darra *et al.*, 1970). However, Sharma *et al.* (1968) while studying the saline and alkali soils in district Pali (Rajasthan) reported sandy to sandy loam texture. These observations suggest that though the zone of maximum accumulation of clay was in the subsurface layers, but the movement of clay to lower layer has not been enough to contribute any appreciable textural change in the soils.

Vinayak *et al.* (1981) studied the alluvium derived sodic soils of Punjab and concluded that particle size distribution suggests that sand is the dominant fraction in the surface horizons which may be attributed to the removal/translocation of finer separates through elluviation or surface erosion. The amount of sand decreases with depth, while the amount of clay increases in B horizon, which again tends to decline in the lower part of the B or C horizon. The uncultivated sodic soils and their cultivated counterparts have comparable texture.

The soil texture of salt-affected soils in district Bhilwara, Rajasthan varied from sandy loam to clay loam with some exceptions in subsurface horizons of moderately saline soils where sandy clay texture was observed by Sharma *et al.* (2004).

2.1.2 Physical characteristics

(A) Bulk density and particle density: Bulk density is commonly used as an index of soil physical conditions and shows stage of mechanical barrier if its value exceeds 1.4 Mg m^{-3}. Wicklund and Whiteside (1959) observed that the A and B horizon have very low bulk density and high percolation rate. They also reported sharp decrease of non-capillary porosity with depth in lower parts of the B horizon. Similarly, Sangwan (1978) reported a higher bulk density in lower horizon, which may be attributed to the finer fraction and heavy minerals alleviated from the surface horizon. Kumar and Kumar (1993) reported that bulk density increases with depth, which is due to increase in compaction caused by cementing agents. Kumar *et al.* (1995) indicated that bulk density of the soils varies from 1.65 to 1.69 Mg m^{-3} while studying the alkali soil on Siwalik Hills of Satluj – Yamuna divide, North – West India. Further, Yeresheemi *et al.* (1997) stated that bulk density values, which showed negative correlation with organic carbon tended to increase with depth and relatively, higher values in comparison with those recorded in the normal soils of the same region. This could be attributed to clogging of pores by dispersed clays in sub soil layers (Mathan and Mahendran, 1994) and reduction of organic carbon with depth. Similar results were also reported by Sharma (2000) while working on salt-affected soils of Bhilwara district of Rajasthan. Durgude *et al.* (2004) while studying sodic soils of Rahuri district, Maharashtra reported that the bulk density of all pedon ranged from 1.52 to 1.80 Mg m^{-3}. The high value of bulk density was due to increase in sodiumized clay content, dispersion and migration of clay.

Yeresheemi *et al.* (1997) while studying the salt-affected soils of upper Krishna Command, Karnataka have observed that the soil particle density did not exhibited greater variations within or among the profiles. Similar results have also been reported by Veerpal (1976) while studying the salt-affected soils of Vallabhnagar, Rajasthan. He has further reported that if there is some variation then it is due to the effect of profile locations. Kumar and Kumar (1993) reported lower particle density in subsurface horizon, which is due to presence of high amount of clays and their saturation with sodium ions. Verma (1995) observed small variation in particle density and reported a higher value in lower horizon than surface ones, which may be attributed due to leaching of salts and heavy minerals. Sharma (2000) obtained almost identical values for particle density and values recorded varies from 2.40 to 2.66 Mg m^{-3} in various horizons, in different groups of salt-affected soils of district Bhilwara.

(B) Water retention characteristics: The maximum water holding capacity of soils was generally related to the texture of the soils and increased with an increase in clay content (Shukla and Raychaudhuri, 1966). Bhaskar and Nagaraju (1998) while studying the salt-affected soils in the Chitravathi river basin (A. P.) inferred that the clay content is positively correlated with soil water content at –33 KPa (r=0.71) and –1500 KPa (r=0.79). The strong relationship of clay with soil water held at –1500 KPa is due to surface adsorptive forces, which do not vary as widely as that of internal surfaces. They have further reported that the soil water held at –33 KPa is a function of clay, silt, organic carbon and bulk density and its relationship (r= 0.55) is expressed as

Soil water content at –33 KPa (Y) = 19.42 + 0.5 (clay %) + 0.34 (silt %) – 0.98 (Organic carbon in g kg^{-1}) – 5.81 (B.D. Mgm^{-3})

Further, plant available water (PAWC) has significant positive correlation with silt plus clay content (r= 0.74) and yielded a regression equation as

PAWC in kg kg^{-1} (Y) = 4.539 + 0.21 (% silt + clay)

Yadav and Vyas (1998) reported that moisture retention at different tension and available water content showed highly positive and significant correlation with silt, clay, silt + clay and bulk density of soil while these showed a negative and significant correlation with sand content. Such behavior of moisture retention in these soils can be attributed to pore size distribution resulting from sand and silt content. Swelling and adsorptive forces associated with silt, clay and organic carbon content of the soils largely control the moisture retention. While studying the soils of semi-arid and eastern Rajasthan. Gajbhiye (1990), Patgiri *et al.* (1993), Yadav *et al.* (1995) and Chatterji *et al.* (1995) also reported similar findings.

Kumar *et al.* (1995) indicated that available moisture content of Ramgarh soils varies from 8.3 to 13.6 per cent and that of Panchkula soils varies from 11.8 to 15.5 per cent. Prasad *et al.* (1998) concluded that the moisture retention at 33 and 1500 KPa in black and alluvial soils was a resultant function of two sets of factors influencing in opposite direction, with one set of factors, CEC, organic carbon, clay, $CaCO_3$ and exchangeable bases on the exchange complex influencing positively, while on the other hand sand fraction influencing negatively. Consequently, the available water content was also influenced by the same set of factors and in a similar manner. Exchangeable Ca^{++}, Mg^{++} and Na^{+} had shown greater influence than exchangeable K^{+} on moisture retention characteristics.

Sharma (2000) while studying salt-affected soils of district Bhilwara observed that the moisture retention at -33 KPa tension was found to be a function of mechanical components of the soils as is manifested by a positive correlation with silt and clay and negative with sand. At -33 KPa tension the moisture content is poorly correlated with organic carbon and soluble salt content of the soil. Similar results were also obtained for water retention at -1500 KPa and available water content.

Challa *et al.* (2000) reported that the water held at -33 KPa and -1500 KPa increases with depth except in Khondwad soils. The relationship of soil water held at -33 KPa with clay and silt content is positive (R^2= 0.66) and yielded a regression equation as:

$$\text{Soil water held at } -33 \text{ KPa } (Y) = 0.64 + 0.48 \text{ (\% silt + clay)}$$

2.1.3 Chemical characteristics:

(A) Soil reaction and electrolyte concentration: The pH of soils has been reported to decrease with an increase in the altitude (Minhas and Bora, 1982; Singh *et al.*, 1991; Sharma *et al.*, 1996).

Kumar *et al.* (1994) observed that the pH of subsurface horizon varied from 8.8 to 10.7 in the pedon. Like that of texture, pH did not vary much with changes in elevation and rainfall in the salt-affected soils of Satluj-Yamuna divide. Further, a gradual increase in pH values from surface to downwards in all profile of Astaranga under study was reported by Sahu and Dash (1993). However, a reverse trend of pH value was noted by Vinayak *et al.* (1981) in alluvium derived sodic soils in Punjab.

Garg *et al.* (2000) reported that the soil reaction was moderately to strongly alkaline in the surface (pH 7.8-9.5) and subsurface horizons (pH 7.9-11.0). A gradual increase in soil pH down the depth of every pedon was discernible except in pedon 2. Sharma *et al.* (2004) reported that the pH ranging from 7.66 to 8.98, which showed an increase with an increase in the salinity except in strongly saline soils of Bhilwara district, Rajasthan. Nayak *et al.* (2000) while working on some salt-affected soils of Bhal region of Gujarat have reported that the soils were slightly to moderately alkaline in nature (pH 7.5 to 8.2). These soils were saline with the ECe ranging from 1 to 132 dSm^{-1}. The salt content was decreasing with depth of profile in all pedons except in Vachhnad (P_4) where it is increasing with depth.

Sangwan (1978) observed much variation in the electrical conductivity in the various physiographic units of Haryana. The salt accumulation in soil profile largely depends on the soil drainage condition, in addition to topographic situation. Salt accumulation was more in areas when high water tables encountered (Pathak and Patel, 1980). However, Raychaudhuri *et al.* (1963) have reported that the general trend of decreasing ECe values with depth indicates that leaching of salts has not occurred from surface to lower depth. Choudhary and Khepar (1972) and Sahu and Dash (1993) have also reported similar results. Kumar and Kumar (1993) while working with soils of Gangetic alluvial tract in western U.P. reported that the neutral pH in Siwaya I soils was due to low amount of exchangeable sodium and the dominance of neutral soluble salts. The higher pH values of Siwaya II and Siwaya III may be attributed to the presence of high amount of exchangeable sodium and the presence of relatively high proportion of soluble salts dominated with sodium bicarbonate and carbonate in soils. Bhaskar and Nagaraju (1998) also reported similar results while working with soils of A.P. The soils were neutral to strongly alkaline in reaction and pH values (7.5 to 9.1) showed an invariable increase with the profile depth possibly owing to decrease in EC and rise in ESP with depth. Comparatively higher pH values (9.0) in some profiles could be due to higher exchangeable and water soluble sodium in those profiles (Yeresheemi *et al.*, 1997). Similarly, Mondal and Sharma (1997) in a study of some salt-affected soils of Indira Gandhi Nahar Pariyojna Command Area, Rajasthan noted that the soils are neutral to slightly alkaline in nature. The ECe values varied from 5.1 to 142.6 dSm^{-1} and pedon 1 located at Lunkaransar Lift Scheme Command suffering from salinity and waterlogging recorded the highest value of ECe (142.6 dSm^{-1}). ECe values were high in the surface horizons and decreased with depth. During the dry period, the water table moves below the root zone leaving behind the salts near the surface leading higher concentration of soluble salts near the surface. Similar findings were also reported by Pathak and Patel (1980) while working in Kaira district of Gujarat.

Dubey and Sharma (1988) in a study of coastal soils of Ahmedabad observed that the pH in all the pedons ranged between 8.0 to 8.9 and no definite trend with either depth or with increase/decrease in exchangeable sodium percentage could be detected. This may be ascribed to the presence of neutral salts, mainly sodium chloride and sodium sulphate. Pedon 1 had low salt content with ECe ranging between 2.8 to 5.2 dSm^{-1}. However, pedon 2 and 3 were highly saline in nature. This may be ascribed to their proximity to the sea and to their physiographic position in the terrain.

Sharma *et al.* (2004) while studying the salt-affected soils of Bhilwara reported that the ECe of the soils under study ranged from 1.84 to 33.20 dSm^{-1} indicating a wide variation. A relatively higher ECe values in surface layer as compared to subsoils were observed except in moderately saline soils.

(B) Calcium carbonate: A high amount of lime in the top soil, which decreased in the sub soil in sand dunes have been reported by Roy *et al.* (1967). Kanwar and Sehgal (1962) observed that the accumulation of calcium carbonate in lower horizon in arid and semi-arid climate and the high amounts of calcium carbonate in the upper horizon due to their formations from calcareous material. They further reported that the calcium carbonate kankar are formed due to exchange of calcium by sodium and subsequent leaching followed by reunion with carbonate and bicarbonate.

Bhargava *et al.* (1981) in the sodic soils of Indo-Gangetic Plain recorded a distinct and massive zone of lime accumulation existing at around one meter depth, whereas the content of lime concentration increases rather vary gradually within the soil profile. A smooth boundary of the calcic horizon, irregular shape of individual nodules or concretions and regular thick zones of accumulation underneath vast areas highlight their pedogenic origin. Sehgal and Stoops (1972) under similar situations also postulated the pedogenic formation of calcium carbonate concretions. In the absence of stratification and lithological discontinuities in these soils, it is not logical to believe that the lime concretions present in these soils will have originated from calcareous particles transported by wind from other parts of Rajasthan. Qureshi *et al.* (1996) while working with saline and sodic soils of Bharatpur observed that the upper part of the control section was found to be free from calcium carbonate in pedon 1 to 3, whereas, accumulation of it, was noticed in lower part of the control section. However, the content of $CaCO_3$ was least affected from the pedogenic activities in pedons P4 and P5 resulting in calcareousness throughout the control section.

Pathak and Patel (1980) observed higher amount of $CaCO_3$ (4 to 16%) in lower layers of most of the salt-affected soils of all the areas in Kaira district of Gujarat. This could be possibly due to the accumulation of displaced Ca from the exchange complex from the upper layer or due to precipitation of $CaCO_3$. Similar findings have also been reported by Joshi and Kadrekar (1987). While working with soils of Rajasthan Mathur *et al.* (1968) observed more $CaCO_3$ content in saline sodic soils and its increasing trend down to profile. Similarly, Vinayak *et al.* (1981) reported the presence of $CaCO_3$ in all the pedons but the calcic horizon within one meter at the surface was observed only in Langarian series of Alluvium derived sodic soils of Punjab.

Tiwari *et al.* (1983) while working with salt-affected soils in central alluvial region of U.P. observed that $CaCO_3$ in surface soil ranged from 0.68 to 3.82 per cent. An accumulation of $CaCO_3$ in lower layer is also visible but trend is not consistent. In an investigation of saline and alkali soils in Haryana, Sharma and Bhargava (1993) noted that the soils are characterized by a 15 to 25 cm thick calcium carbonate concretion layer at around 1 m from the surface.

Bhattacharya *et al.* (1994) reported that soils having more than 15 cm thick horizon with carbonate content equivalent to more than 15 per cent $CaCO_3$ and containing appreciable amount of soft powdery lime, indicate the presence of calcic horizon. Identification of such horizon calls for grouping these soils in *Calciusterts* at the great group level.

Verma *et al.* (1995) while working with salt-affected soils of Etah district reported that the soils are highly calcareous ($CaCO_3$: 1.4 to 24.7%) and show progressive downward increase of lime and formation of Kankar pan. Kumar *et al.* (1995) also reported calcareous alkali soils ($CaCO_3$: 0.5 to 9.2%) in Siwalik Hills of Satluj-Yamuna divide, Northwest India.

Garg *et al.* (2000) while studying sodic soils of Gangetic plains at Banthra, Lucknow observed lower amount of $CaCO_3$ in surface soil ranging from 0.13-8.4 g kg^{-1}, which gradually increases with depth. Similar results were also reported by Nayak *et al.* (2000) and Challa *et al.* (2000).

Sharma *et al*. (2004) observed that the calcium carbonate content of the pedons under study ranges from 30.1 to 249.1 g kg^{-1}, increased with depth which explains downwards movement of calcium and its subsequent precipitation as carbonate.

(C) Organic carbon: Due to favourable environment for the luxurious vegetation higher amount of organic carbon content has been found in the areas of high rainfall and low temperature, however, at high temperature the organic matter content was found to be low due to the rapid oxidation of organic residues (Minhas and Bora, 1982). Sharma. *et al.* (1986) and Sahu and Dash (1993) reported low organic carbon content of soils due to sparse vegetation coupled with high rate of organic matter degradation under hyperthermic temperature regime.

Soil Survey Staff (1983) recorded a zone of maximum of organic carbon below the plough layer, which coincided in the plough layer or slightly above the zone of maximum clay accumulation. The higher concentration of organic carbon in this zone was due to the storage of moisture for a longer period inviting the concentration of more amounts of secondary roots or rootlets. However, saline and alkali soils, in general, have low organic carbon content in their soil profile (Kumar *et al.*, 1995; Tiwari *et al.*, 1983; Bhargava *et al.*, 1981; Mondal and Sharma, 1997). Qureshi *et al.* (1996) while working with saline and sodic soils of Bharatpur observed a low but uniform distribution of organic carbon along the depth of the profile confirmed the homogeneity of parent material. The soils of Andhra Pradesh show decreasing trend of organic carbon with depth except Buruzupalli soils (P_2) where organic carbon content of 2 to 3 g kg^{-1} was observed at a depth of 0.57 to 1.5 m (Bhaskar and Nagaraju, 1998).

Kumar and Kumar (1993) while studying salt-affected associated soils of Gangetic alluvial tract in Western Uttar Pradesh observed that Siwaya I and Siwaya III have more organic carbon as compared to Siwaya II. In general, low organic carbon content is due to poor vegetation and rapid decomposition and mineralization of organic matter under high temperature and low rainfall.

The salt-affected soils of Bhal region of Gujarat show decreasing trend of organic carbon with depth which ranges from 4.5 to 0.1 g kg^{-1} (Nayak *et al.,* 2000). Similar result was also observed by Garg *et al*. (2000) while studying sodic soils of the Gangetic plains of Banthra, Lucknow and Sharma *et al.* (2004) while working with salt-affected soils of Bhilwara district, Rajasthan, reporting a range between 7.7 to 3.21 g kg^{-1}.

(D) Water soluble ions: The soluble salts in saline soils mainly comprise the chlorides and sulphates of sodium, though calcium and magnesium are also present in appreciable quantities (Dargan *et al*., 1982). The proportion of magnesium is usually higher than that of calcium. Higher concentration of magnesium than that of calcium cause harmful effects on the physical properties of soils and crop growth (Yadav and Girdhar, 1980, 1981). Bicarbonate ion occur in very low amounts and carbonates are usually absent or occur only in traces in these soils (Dargan *et al*., 1982).

Sahu and Dash (1993) observed that sodium and calcium are the most dominant cations in the saturation extract obtained from the salt-affected coastal soils of Astaranga, Orissa. The proportion of magnesium increases in lower layers of pedon 3 and 4 due to their prolonged contact with marine brackish water, which has appreciable amount of chloride, a predominant anion followed by sulphate indicating the salts to be mostly of chloride and sulphate type of sodium with lesser quantity of calcium and magnesium in soils of coastal Orissa.

Bhargava *et al.* (1981) while studying the sodic soils of Indo-Gangetic alluvial plains of Haryana concluded that sodium alone nearly account for the cations, while among the anions the order of decreasing abundance is bicarbonate, carbonate, chloride and sulphate. Similarly, Tiwari *et al.* (1983) indicated that in salt-affected soils of alluvial regions of U.P. Sodium (dominant cation) is generally more in the surface soils. Carbonate happens to be the dominant anion followed by bicarbonate, chloride and sulphate in all the profiles except Bara where bicarbonate is dominant followed by chloride, carbonate and sulphate. In this way, the bulk of cations and anions are consisted of sodium carbonate and bicarbonate.

Yeresheemi *et al.* (1997) observed that soil-water cationic composition, as opposed to exchange surface, was dominated by sodium, however, concentration of water soluble calcium remained nearly close to that of sodium. Among the anions, although chloride were the dominant, sulphates were also present in almost similar quantities, indicating the chloride, sulphate type of salinity in salt-affected soils of upper Krishna Command, Karnataka.

Challa *et al.* (2000) while studying problematic vertisols in semi-arid ecosystem of Mahrashtra plateau reported that among water soluble cations sodium is dominant and increases with depth. The associated anions are mainly chloride and bicarbonate which show increasing trend with depth. The calcium concentration decreases as soil water gets reduced.

Sharma *et al.* (2004) while working on salt-affected soils of Bhilwara district, Rajasthan observed a preponderance of sodium among cations and chloride among anions, while the contents of calcium and magnesium were almost comparable in magnitude. The carbonate was almost negligible while bicarbonate and potassium were present in lower amount.

(E) Cation exchange capacity (CEC): The cation exchange capacity of soils is also a very important property in relation to nutrient supplying power of the soil. Joffe and Kunin (1943) found that clay was only important fraction for CEC in the soils formed from igneous rock materials. Mohamed and Gohar (1960) observed that silt and sand sized particles also contribute to CEC in addition to clay and organic matter, however, Lavati *et al.* (1969) observed negligible role of silt and sand sized particles towards cation exchange capacity. Deshmukh and Bapat (1993) also suggested that the value of CEC have a close relationship with the per cent clay content. CEC of saline-sodic soils ranged from low to high and showed increasing trend with clay as well as depth of profile in different studies (Pathak and Patel, 1980; Sahu and Dash, 1993; Sahu *et al.*, 1986; Kumar and Kumar, 1993; Mondal and Sharma, 1997). Dubey and Sharma (1988) while working with salt-affected soils of Ahmedabad observed that the CEC values corroborated well with the clay content and indicated dominance of smectite in the clay.

Qureshi *et al.* (1996) found no specific pattern of distribution of CEC, suggesting mixed mineralogical composition of the saline and sodic soils of Bharatpur. Further, several workers suggested that CEC values were significantly related to clay per cent indicating major contribution for CEC from inorganic fraction than organic sources which is comparatively low in such soils (Sahu and Dash, 1993; Yeresheemi *et al*., 1997; Challa *et al.*, 2000).

Sharma *et al.* (2004) while working on salt-affected soils of Southern Rajasthan reported that the CEC exhibited a narrow range [13.97 to 16.49 cmol(P^+) kg^{-1}] in non-saline soils as compared to saline soils [12.95 to 28.41 cmol(P^+) kg^{-1}] as a consequence of variation in their clay fraction. The CEC values, in general, increased in subsurface horizon of the pedons as compared to surface horizon except the non-saline soils. The CEC observed in these soils is essentially contributed by their clay content, since the soils of the region are low in organic carbon content.

(F) Exchangeable cations: A decrease in the calcium content with the depth has been reported by Parsons and Balster (1966) except few exception, which was attributed to nutrient cycling by vegetation. Further, the content of exchangeable calcium and magnesium were found to increase down the slope (Gawande *et al*., 1967 and Datta *et al*., 1990). The Ca^{2+} and Mg^{2+} were the dominant cations on the exchange complex of all the saline and sodic soils of Bharatpur except in the pedon 4 (loamy soils), *Aeric Halaquepts* where Na^+ was dominant over others (Qureshi *et al*., 1996) and comparatively narrower Ca^{2+}/Mg^{2+} ratio was registered in pedon 2 to 5, which might be attributed to the extreme suppression of calcium solubility, substitution of Mg^{2+} for Ca^{2+} by plants and recycling of unusual amount of Mg^{2+} (Wilding *et al.*, 1963). The variation in Ca^{2+}, Mg^{2+} and K^+ content among the profiles was found to depend on topography and parent materials (Martini and Mosquera, 1972). Exchangeable bases have been reported to be high in the soil profile, which decreases with depth due to large amount of biomass returning to the soil surface in addition to the phyllitic materials, rich in Ca^{2+} and Mg^{2+} (Ramana Murthy and Sharma, 1992). Khurana (1972) reported exchangeable potassium to vary from 0.2 to 0.4 me $100g^{-1}$ alongwith a dominance of calcium and magnesium in a salt-affected soil profiles of Rajasthan.

Pathak and Patel (1980) while working on salt-affected soils of Kaira district of Gujarat reported that for the Thasra area, in general, the order of exchangeable cations was $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$, while in soils of Matar, a coastal area, the order was $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$, indicating a considerable amount of Na^{+} has gained entry into the soil exchange complex. Similarly, Sahu and Dash (1993) while working on salt-affected coastal soils of Astaranga, Orissa observed that Ca^{2+} dominates the exchange complex of pedon 1 and 2 except the last two layers of pedon 2 where Mg^{2+} is higher indicating the influence of ground water. However, Verma *et al.* (1995) while studying the soils of Etah district registered Na^{+} as dominant cation in all the mapping units showing an increasing trend from S_1 (low sodicity) to S_4 (high sodicity).

Kumar and Kumar (1993) while studying the salt-affected soils of Gangetic alluvial tract observed that sodium is the dominant cation in Siwaya II and Siwaya III soils. The amount of exchangeable sodium is also being exhibited by the higher values of ESP and pH in these soils. Siwaya I soils dominated by calcium. However, Yeresheemi *et al.* (1997) while studying upper Krishna Command Area in Karnataka recorded together, Ca^{2+} and Mg^{2+} accounted for greater portion of soil CEC and exchangeable Na^{+} was the next in order of dominance.

Challa *et al.* (2000) reported that Ca^{2+} is dominant cation in exchange complex and next to Ca^{2+} is exchangeable Na^{+}, which shows increasing trend with depth. The exchangeable Mg^{2+} shows irregular trends in distribution with depth in problematic soils of Ahmednagar and Akola districts of upper and lower Maharashtra plateau.

Garg *et al.* (2000) while working on sodic soils of the Gangetic plains at Banthra, Lucknow reported that Ca^{2+} and Mg^{2+} were dominant cations followed by Na^{+} and K^{+} ions on the surface soils. Likewise, Sharma *et al.* (2004) also observed that among the exchangeable cation, Ca^{2+} dominates the exchange complex followed by Mg^{2+} which dominates over Na^{+}. It was also observed that as the finer fraction increased, there was a corresponding increase in content of exchangeable bases.

(G) Exchangeable sodium percentage and sodium adsorption ratio: Sharma *et al.* (1968) while working with soils of Pali district, Rajasthan reported that exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) values were high in irrigated profiles and ranged from 7.2 to 21.1 and 9.25 to 146.6, respectively. For unirrigated soils the value varies 5.1 to 18.1 and 0.14 to 22.2. There is no regular trend of ESP and SAR correlation, which indicates that equilibrium has not been established in the soils under the field conditions. Similarly, Darra *et al.* (1970) have also reported high ESP and SAR in irrigated tracts, ranging from 7.20 to 22.00 and 4.34 to 38.19, respectively. In the unirrigated tracts these values were low, varying from 0.18 to 15.00 and 0.67 to 14.36, respectively, except the last layers, where the values were high, however, no correlation between SAR and ESP was observed. Contrary to this Kolarkar and Singh (1970) recorded the values of SAR of the saturation extract of the samples and correlated with the determined values of the ESP. The relationship between SAR and ESP indicates that SAR can also be taken as an index for appraisal of ESP status in saline sodic soils.

While, studying the soils of Kaira district of Gujarat state, Pathak and Patel (1980) reported that ESP varied between 1.28 to 46.9; 5.0 to 72.5 and 7.5 to 67.5 in the soils of Thasra, Matar and coastal areas, respectively. Similarly, higher values of ESP (>15.0) were also reported by Sahu *et al.* (1986) in coastal saline soils of Orissa. Contrary to this while working on salt-affected soils of Astaranga, Orissa Sahu and Dash (1993) and alkali soils of Ghaggar river basin of Satluj - Yamuna divide of NW-India Kumar *et al.* (1994) recorded ESP value less than 15.0.

Yeresheemi *et al*. (1997) while working on salt-affected soils of Upper Krishna Command, Karnataka reported that, in general, ESP of soil increase with depth and ranged between 8.7 to 25.8. The tendency of ESP to increase with the depth indicates the beginning of the sodification process in subsoils. Similar results were also observed in Vertisols of the Purna valley of Maharashtra by Balpande *et al.* (1996).

Challa *et al*. (2000) reported that the ESP of soil increased with depth and have a significant positive relationship with pH of soils and yielded a regression equation of pH = 8.15 + 0.012 (ESP). The SAR also increased with depth in salt-affected soils of Ahmednagar and Akola district of upper and lower Maharashtra plateau.

While working on black soils of Bhal region of Gujarat, Nayak *et al.* (2000) reported that soils from Kalamsar and Saragwad were showing high SAR and low ESP. The high SAR during summer months may cause the soil dispersion and ultimately deteriorate the soil structural stability. Although ESP and SAR levels, in general, have excellent relationship with structural stability when sodium levels are artificially adjusted to single soil sample, but it does not provide a rational for favouring relative indices of sodicity over absolute indices of sodicity

(Cook and Muller, 1997). Increase in ESP with depth was also observed by Garg *et al.* (2000) in sodic soils of the Gangetic plains at Banthra, Lucknow.

While working on salt-affected soils of district Bhilwara, Rajasthan Sharma (2000) reported that ESP and SAR values of the soils under study exhibited statistically a positive relationship with 'r' value 0.73. However, the SAR values of the soils were of low magnitude (1.29 to 11.91) as compared to the ESP values (6.09 to 45.06), indicating a poor establishment of equilibrium between water soluble and exchangeable cations in the soils under field condition. The probable reason for this is that while extracting saturation extract of calcareous salt-affected soils the calcium of $CaCO_3$ comes under soil solution and decreases SAR of the soil.

2.2 SOIL CLASSIFICATION

A classification of soils should be such that it can be applicable to all the soils including soils, which have been disturbed by cultivation or erosion. Soil classification into order, sub-order, great soil group etc. was presented by Baldwin *et al*. (1938). This system being generally followed in many countries including India. The classification is however, not perfect as the definition of soil properties are brief and not sufficiently defined. A number of systems of soil classification are adopted in different parts of the world, including the recent one evolved in USA the Comprehensive System of Soil Classification designated as Soil Taxonomy (Soil Survey Staff, 1999). Some of these classifications are briefly reviewed in this section.

2.2.1 Russian classification

The soil classification followed in USSR is a genetic system based on strong genetic emphasis evaluating soil properties and the pedogenic processes in the solum in relation to various soil forming or pedogenic processes and the agents or factors of soil formation (Razav and Ivanova, 1968). This approach has been designated as "ecological genetic classification" by some of the Russian soil scientists. The point of emphasis in the system is the action of soil forming factors to produce soil properties in profiles called "soil type". The categories of this system comprised of: class, type, sub-type, genera, species, varieties, rank and phase.

2.2.2 Soil Taxonomy

The Soil Conservation Service, USDA under the leadership of G. D. Smith, started a completely new system in design and nomenclature, above the levels of soil series. The development of this new comprehensive system was by a series of approximation, which were circulated for criticism and comments. The 7th approximation was published in 1960 to ensure wider circulation and hence a broader spectrum of comments received and further studies were used as a basis for supplements published in 1964, 1967 and Soil Taxonomy in 1975.

In the 4th edition of Key to Soil Taxonomy (Soil Survey Staff, 1990), the colour limit for soil chroma became 2 rather than 1.5. However, the system of classification fails to reflect accumulation of carbonate, gypsum, soluble salts and building of sodium, which are important from the utilization point of view.

The 5th edition of Key to Soil Taxonomy (Soil Survey Staff, 1992) again contained significant changes in soil taxonomy to resolve the above pending issues. The Vertisol order in 5th edition has 6 suborders, 23 great groups and 153 subgroups. The great group categories have a morphogenetic bias by considering properties, such as salt accumulation (Salic, Natric, Calcic and Gypsic great group), silica accumulation (Duric great group), depth of saturation by water (Epi and Endo great group). Finally, 153 categories are distinguished at the subgroup level in this edition of Key to Soil Taxonomy (Soil Survey Staff, 1992). Variation in status of vertisols classification is not proposed in 6th, 7th (Soil Survey Staff, 1995), and 8th (Soil Survey Staff, 1998) edition of Key to Soil Taxonomy.

The system is well recognized, logical and presents a natural system of soil classification. In this system soil scientists try to approach a natural classification as an ideal and more weightage is given to properties of higher agriculture relevance. Criteria used are comparatively clear, not arbitrary and the system has a well defined boundary. The definitions of the texa are precise and quantitative rather than comparable and are written in "operational terms". It has wide applicapabilities and highest category is placed on the basis of soil of whole landscape. It is capable to accommodate most of the world soils.

2.2.3 Classification of salt-affected soils

(A) USA: As early as 1907 Hilgard put forth one of the earliest classification of salty land. He divided alkali soils into the following two classes based on the composition of salt and general appearance of the soil.

(i) White alkali, containing chloride and sulphate of sodium,

(ii) Black alkali, containing sodium carbonate as the predominant salt

USSL published a Handbook No, 60 (Richards, 1954), in which the problem soil under consideration have been separated into three groups; saline, saline-alkali and non-saline alkali soils.

Saline soils: Saline is used in connection with soils for which thc conductivity of the saturation extract is more than 4 mmhos cm^{-1} at 25°C and the exchangeable sodium percentage is less than 15, ordinarily pH is less than 8.5. These soils correspond to Hilgard's (1907) 'white alkali' soils and to the 'Solonchak' of the Russian classification.

Saline-alkali soils: Saline-alkali is applied to the soils for which the conductivity of the saturation extract is greater than 4 mmhos cm^{-1} at 25^0C and the exchangeable sodium percentage is greater than 15. These soils are formed as a result of the combined processes of salinization and alkalization. As long as excess salts are present the appearance and properties of these soils are generally similar to those of saline soils. Under conditions of excess salts, the pH reading is seldom higher than 8.5 and the particles remains flocculated.

Non-saline-alkali soils: Non-saline-alkali is applied to the soils for which the exchangeable sodium percentage is greater than 15 and the conductivity of saturation extract is less than 4 mmhos cm^{-1} at $25^{0}C$. The pH reading usually ranges between 8.5 and 10.0. These soils correspond to Hilgard's "black alkali" soils and in some cases to solonetz, the term used by the Russians.

Soil Survey Division Staff (1995) inferred the salinity as non-saline (ECe 0-2 dS m^{-1}), very slightly saline (ECe 2-4 dS m^{-1}), slightly saline (ECe 4-8 dS m^{-1}), moderately saline (ECe 8-16 dS m^{-1}) and strongly saline (ECe >16 dS m^{-1}). Further, for the sodicity SAR is the standard measure of a soil. Formerly, the ESP which equals to exchangeable sodium (me $100g^{-1}$ soil) divided by the cation exchange capacity (me $100g^{-1}$ soil) time 100, was the primary measures of sodicity. The test for ESP, however, has proven unreliable in soils containing sodium silicate minerals or large amount of sodium chloride.

The Soil Science Society of America (1974) has modified the definition and classification of salt-affected soils. The critical limit of ECe has been reduced from 4 dS m^{-1} to 2 dS m^{-1} and criterion of ESP has been replaced with SAR, critical limit of 15 remaining the same. Accordingly, a soil is having ECe greater than 2 dS m^{-1} is defined as saline. The soil may have any values of SAR and pHs. A soil having SAR greater than 15 is defined as alkali/sodic. This soil may have any values of ECe and pHs. A soil having ECe more than 2 dSm^{-1} and SAR more than 15 and pHs ordinarily less than 8.5 is defined as saline-alkali (saline-sodic soils).

In Hungary and other European countries (Somani and Totawat, 1993), salt-affected soils have classified in two classes as described below:

Saline soil : The soils contain sufficient amount of neutral salts to adversely affect the growth of most crop plants. The salts are mainly chlorides and sulphates of sodium followed by those of magnesium and calcium (ECe 4 dS m^{-1} occurring within 125, 90 and 70 cm below the surface in case of coarse, medium and fine textured soils, respectively).

Alkali soil : The soils contain sodium salts capable of alkaline hydrolysis, mainly Na_2CO_3 or $NaHCO_3$ or dominated by exchangeable sodium (ESP 15). The alkali soils have been sub-divided into two groups *viz.*, (i) without structural B horizon and (ii) with structural B horizon.

(B) Russia: In Russia as early as 1912 salty lands were classified into three categories: (i) solonchak (ii) solonetz and (iii) solod.

Solonchak: Solonchak is the first stage in the evolution of alkali soils and corresponds closely to saline soils of other countries. There can be an active solonchak connected to ground water through capillary fringe or residual (dry) solonchak with deep ground water in extreme arid locations. The composition of the predominant salts may differ, rather widely, from place to place.

Solonetz: A series of reaction takes place concurrently with the salinization of soil profile. If the soluble cations consists predominantly of sodium, considerable Ca^{2+}, Mg^{2+} and K^{+} are displaced from the exchange positions of the clay complex and sodium get adsorbed as a result of base exchange. The process is known as alkalization and the soil passes to the saline-alkali stage. Considerably movement of the salts may take place subsequently, either upwards to the surface by evaporation or downwards by leaching. Consequent removal of the excess salts brings about a process of desalinization accompanied by significant changes in the constitution and construction of soil profile.

As the excess salts are leached down, the soil colloids get dispersed and move to the sub soil making it dense and compact in the presence of free $CaCO_3$ or even in the absence of free calcium carbonate hydrolysis of sodium-clay takes place resulting into formation of sodium carbonate. The sodium carbonate so formed, even react with any calcium clay when comes in contact, converting it into sodium clay and precipitating calcium carbonate. This results into formation of strongly alkalized soils. Hydrolysis may even bring about the formation of silica gels. These together with humates may work as cementing agents in producing a hard pan in the sub soil or help to develop the structure of the B-horizon, which is characteristic of the solonetz morphology.

Typologically, Russian solonetz profile demands the following characters: A-over solonetz horizon; B_1-solonetz horizon; B_2-carbonate horizon; and finally the salt horizon. Solonetz or typical alkali soils may thus posses many characteristics: (i) low contents of clay and salt at least in the upper part of the profile, (ii) high exchangeable sodium at least in the B-horizon, (iii) dense character of the B-horizon due to the accumulation of clay and other products of weathering with pronounced columnar structure, and (iv) resting on an underlying horizon with large quantities of calcium and magnesium carbonates. Categorization of solonetz soils has been attempted on the basis of the degree of solonetz of the B horizons.

Solod: It is further stage in the development of alkali soils, whereby degradation starts due to intensive leaching of sodium ions and consequent replacement by hydrogen ions in the upper part of the profile. The degradation is conspicuous in depression and high rainfall areas. Here in these types of soils the pH may go even below 6 but yet contain enough sodium to give an unstable structure. As the replacement with hydrogen ions proceeds at the surface, the base exchange material becomes progressively unstable. Amorphous silica separates out at the surface giving an ash-gray colour and platy structure. Exchangeable sodium and magnesium may accumulate in the lower part of the profile alongwith iron and aluminum oxides.

(C) India: In ancient India (2500 B.C. to 600 A.D.) the soils were divided into two classes, *viz.* urvara (fertile) and unurvara (sterile or unfertile). Urvara soils were subdivided into different kinds with respect to crops, for example Java (Barley), Tila (Sesamum), Urnhi (Rice), etc. Unurvara soil was subdivided into Usar (salt) and Maru (desert).

Raychaudhuri (1963) classified saline and alkali soils of India into four categories (i) saline (ii) saline-alkali (iii) alkali and (iv) degraded alkali.

Murthy and Landey (1967) classified saline-alkali soil profile into 'Soudukhar and Jough' based on the field morphological characteristics and physico-chemical properties and mapped for the Tungbhadra watershed. Such classifications are more practical and useful for farmers and planners. Sehgal *et al.* (1975) classified saline-sodic soils of Indo-Gangetic plain in North West India and reported natric subgroup within the Inceptisols, Alfisols and Aridisols, having high sodium saturation and high EC and ESP values. Further, they have noticed new sub group salic and saline natric within the Aridisols.

Murthy *et al.* (1980) inferred that saline and alkali or sodic soils occur in association with their normal counterparts and as inclusions classified in the great groups. From the soil survey conducted in different regions, from the available literatures gathered and through personal communications, pedon descriptions were reviewed and soils were classified by making modifications, where necessary. Classification was first done at the family level, based on morphological and analytical data. At places, assumptions were made in the light of the author's experience and personal discussions. Information, thus collected, was abstracted and synthesized to prepare a generalised map, showing the distribution and classification of salt-affected soils at the great group-association level. They are:

1. Salorthid - Natrargid
2. Haloquept - Saline phases of Ustochrepts
3. Haloquept - Salorthid-saline phases of Chromusterts
4. Salorthid - Gypsiorthid
5. Haloquept - Saline phases of Ustochrepts, Chromusterts
6. Natraqualf - Natrastalf - Haloquept - saline sodic phases of Calciorthid, Haplorgid, Camborthid, Ustochrept
7. Haloquept - Saline phases of Ustochrept, Haloquept, Fluvaquent
8. Haloquept - Saline phases of Haplaquept
9. Saline or sodic phases of Pallustert, Chromustert, Ustifluvent, Ustropept, Natrustalf
10. Tropaquept — Fluvaquent (acid sulphate)
11. Haplaquept (acid sulphate)

12. Saline phases of Fluvaquent

Dubey *et al.* (1983) classified salt-affected soils of southwest Mehsana, Gujarat into Typic Natrargids, Natric Cambiorthids, Natrustalfs and Halaquepts. Sahu and Dash (1993) categorized the salt-affected soils of Astaranga into Fluvaquents and Haplaquents. Sahu *et al.* (1986) classified the coastal saline soils of Orissa into Vertic and Typic Halaquepts. Dubey and Sharma (1988) categorized the salt-affected coastal soil of Ahmedabad district of Gujarat and reported the characteristic properties of Natric Camborthids developed on the juncture of lower piedmont and flood plains, Typic Salorthids developed on tidal deposits, and Vertic Halaquepts on mudflats.

Jha and Sharma (1989) conducted a comparative studies of two salt-affected and two adjacent normal soils in Bihar. The saline or saline alkali phases were classified as Ustifluvents whereas normal soils qualified as Udifluvents. Kumar and Kumar (1993) classified the salt-affected soils of Gangatic alluvial tract in western U.P. as Typic Ustochrepts, Typic Natrustalfs and Typic Natraqualfs. Bhattacharya *et al.* (1994) classified the saline sodic soils of coastal plains of Gujarat as Halic Calciusterts and Sodic Calciusterts at the great group level.

Similarly, Abrol *et al.* (1988) concluded that experimental determination of exchangeable sodium percentage is tedious, time consuming and subject to errors. Incomplete removal of index salt solution during the washing step of CEC determination can lead to high CEC values and therefore, low ESP estimates. Similarly, hydrolysis of exchangeable cations during the removal of the index salt solution, fixing of ammonium ions from the index of replacement solution by the soil minerals and the dissociation of calcium carbonate or gypsum in the index or replacing solutions can all lead to low values of CEC and therefore to high ESP estimates. Problems of CEC and ESP determinations are also encountered in soils of high pH containing zeolite minerals. These minerals, e.g. analcime, contain replaceable monovalent cation used as the index of replacement cation resulting in usually high values of ESP (Gupta *et al.*, 1984). To overcome some of these difficulties several workers prefer to obtain an estimate of ESP from an analysis of the saturated soil extract. Workers at the USSL (Richards, 1954) proposed that the SAR of the soil solution adequately defines the soil sodicity problem and is quantitatively related to the exchangeable sodium percentage (ESP) of the soils.

The western part of Rajasthan is occupied by sandy soil (Gupta, 1958). However, some of the soils contain high percentage of soluble salts, posses high pH, low loss on ignition, varying percentage of $CaCO_3$ and are poor in organic matter (Raychaudhuri, 1953). The Rajasthan State has all types of saline and alkali problems constituting roughly 15 per cent of cultivated area (Mathur *et al.*, 1968).

Taylor (1955) and Shankaranarayana *et al.* (1965) found that soils were poor in nitrogen, medium in phosphorus and medium to high in potash. The soils were further characterized by incomplete leaching of soluble salts, ill-defined profile development and very poor in humus content (Jain, 1968). The revenue department classified Rajasthan soils based on irrigation facilities and socio-economic consideration into Barani (Rainfed), Chahi (well irrigated), Nahri (canal irrigated), Sailabi (moistened by river seepage), Oran (wasteland or general grazing land) etc. Mehta (1962) stated that Rajasthan state has all types of saline alkali problems and classified them into (I) saline water and alkaline soils (ii) alkali soils (iii) saline water and alkaline patches and (iv) saline and alkali soils.

The term saline-alkali is commonly used, particularly in US when a soil has both high ESP and high electrical conductivity of the saturation extract. The term implies that the soil has problems of high osmotic pressure arising from high salt content and of likely poor physical conditions when excess salts are leached out. The use of the term saline-alkali or saline-sodic is a confusing one and should be avoided. The two categories saline and the saline-alkali are essentially not different from each other and that classifying both these as saline will be more appropriate (Somani and Totawat, 1993).

Raychaudhuri (1964) also reported classification of western Rajasthan soils into four groups (I) pedocal sierozem of alluvial origin (ii) pedocal brown soil of alluvial origin, (iii) gray brown (desert) soils, and (iv) desert soils. While, Satyanarayan (1964) has classified Rajasthan canal area into six classes as follows:

Class I	Flat area presently under cultivation
Class II	Flat area with high pH and excessive salt
Class III	Area intercepted by sand dunes
Class IV	Send dunes area
Class V	Flat area with gypsum pan after 3 to 4
Class VI	Kankar areas

Seth (1967) classified some typical salty lands of Rajasthan into three groups of alkalinity and three groups of salinity according to pH and EC, respectively. Mathur *et al.* (l968) classified soils of Rajasthan based on a broad reconnaissance survey into eight groups (i) desert soils, (ii) gray brown soils, (iii) gray brown soils of river basin, (iv) undifferentiated alluvial soils, (v) mixed red and black soils, (vi) red loam (shallow soils), (vii) red and yellow soils, and (viii) medium black soils.

Roy *et al.* (1973) grouped desert soils of Rajasthan into following great groups (i) desert soils, (ii) sand dunes and sand deposite (iii) red desertic soils, (iv) sierozems, (v) red and yellow soils of foot hills, (vi) saline and sodic soils in depression, (vii) lithosols, and (viii) regosols. Desert soils fall under land capability class VI and VII where good pasture can be had only under careful management. When rainfall is somewhat higher, these soils fall under class III and IV (Roy *et al.*, 1973).

The soils of Rajasthan belong to 5 orders, 8 sub-orders, 16 great groups, 32 sub-great groups and 86 families. Entisols are dominantly observed covering around 36 per cent followed by Inceptisols, Aridisols and Vertisols, covering 22.8, 19.5 and 2.3 per cent of total geographical area, respectively; the Alfisols are least represented covering 0.73 per cent area (Shyampura and Sehgal, 1995).

2.3 LAND USE PLANNING

2.3.1 Soil site characteristics

Most of the plant species need well drained, moderately fine to medium textured soils, free of salinity and having optimum physical environments. Soil map based on several parameters, can aid in predicting the behaviour and suitability of soils for growing crops (agriculture) and/or alternate farming once a criterion for suitability is established. Within limits, it may also find application in other areas with comparable soil site characteristics.

Several systems of land evaluation have been proposed for use in different regions, the important being that of Storie (1954) and Ricquier *et al*. (1970). The FAO panel for land evaluation (FAO, 1976) defined the concept of land utilization types and suggested the classification of land for specific use which was latter on modified by Sys *et al*. (1991). The classification itself is presented in different categories i.e. order, classes, subclasses and units. There are two orders (S for Suitable and N for Unsuitable land), indicating the kind of suitability. There are 3 classes (S_1, S_2, S_3) under the order S and 2 classes (N_1, N_2) under the order N reflecting degrees of suitability within the order. The appraisal of classes, within an order is done according to evaluation of land limitations. The sub-class reflects the kind(s) of limitations or the many kinds of improvement measures required within classes. The soil site parameters considered for the purpose of evaluating land for agriculture and forestry and for defining available moisture, resistant to erosion, water availability, foot hold to root development are enlisted hereunder:

(i) Climate (c)

(ii) Topography (t)

(iii) Wetness (w)

- drainage
- flooding

(iv) Physical condition (s) of soil

- Texture
- Gravel/stoniness
- Depth
- Calcium carbonate
- Gypsum

(v) Soil fertility (f)

- Organic matter
- Cation exchange capacity
- Base saturation
- Nutrient availability

(vi) Salinity and alkalinity (n)

- Salinity
- Ground water depth and its quality
- Alkalinity/sodicity

2.3.2 Crop suitability

A best crop rotation is one, which not only provides good returns but also help to control salinity of the soil. Saline-alkali or alkali soils resulting from irrigation of poor quality water need introduction of crops having high water requirement (Bains, 1971).

Kelley *et al*. (1949) reported a tendency of salts to accumulate when alfalfa is grown because the permeability of the soil permits application of just sufficient water to meet high ET demands of the crop. However, when copiously irrigated vegetable crops are grown during winter (low ET) following alfalfa, any salt accumulated in the ridge of soil when row crops irrigated in furrow are grown, but are leached out subsequently when the soil surface is smoothed and a subsequent crop is grown by flood irrigation. Rice is particularly useful crop to include in a rotation for salinity control, especially on soils having low permeability because it is grown under flooded conditions.

Basu and Tagore (1943) tried several crops on mild alkali soils of Deccan canal area for two years. Crops like rice, berseem and dhaincha significantly increase the exchangeable calcium content of the soil. Exchangeable sodium was lowered in all the cases with berseem and dhaincha giving the highest figure. From increase in Ca/Na ratio, the order of superiority in ameliorating alkali character was found to be: berseem > rice > dhaincha > cotton > jowar > tobacco > wheat.

Kanwar (1969) suggested the possibility of introducing sugarbeet in crop rotation for salt-affected soils. Unlike sugarcane, sugarbeet occupies the land for a comparatively shorter time and can be fitted in the double cropping scheme.

NBSS & LUP (1995) gave the soil-based land use planning series and reported that in Udaipur district (Rajasthan) about 28 per cent of the area is highly suitable and 10 per cent area is moderately suitable for wheat, while, about 40 per cent area is under not suitable class. Similarly for maize cultivation, it was revealed that the highly suitable class covers 11.9 per cent and moderately suitable class covers 35.3 per cent of the total area of the district. Rest of the area is either marginally suitable or non-suitable. Further, they have suggests the following alternate use as well as corrective measures:

1. Afforestation in rocky skeletal area,
2. Development of wild life sanctuaries and forest in non-arable land classes,
3. Suitable soil conservation measures for erosion-prone areas,
4. Amelioration and reclamation of saline sodic soils, and
5. Suitable cropping and water management practices.

Padole and Deshmukh (1998) while studying the salt-affected soils of Purna valley of Vidarbha, Maharastra used different approach for soil site suitability for alternative uses and concluded that all the interpretative system indicated that the soils *viz.* sodic Haplusterts and sodic Calciusterts are marginal for cotton. These soils have main constraints of high ESP with imperfect to poor drainage, very low hydraulic conductivity, AWC and $CaCO_3$. The soils *viz.* Aridic Haplusterts and Aridic Calciusterts are moderately suitable for cotton due to moderate limitation of drainage, AWC and $CaCO_3$. These soils have high potential and can be used to its optimum potential with some management corrections such as improvement of internal drainage, timely tillage operations, use of organics, use of gypsum in sodic conditions, provision of mulch, soil and water conservation method, appropriate selection of crops, proper crop rotation, selection of salt tolerant crops etc.

2.4 QUALITY OF WELL WATERS AND THEIR SUITABILITY FOR IRRIGATION

The concentration and composition of dissolved constituents in water determine its quality for irrigation uses. Quality of water used for irrigation governs the rate and degree of development of soil salinity or alkali condition in an irrigated area in arid and semi-arid regions particularly the Thar Desert areas of Rajasthan, Gujarat, Haryana and Punjab, where ground water is available but the quality is questionable or unsatisfactory. Such areas have limited supplies of surface waters and have low rainfall. Thus, the use of ground water is essential to grow crops, and the management of poor quality water would play an important role.

The important characteristics of irrigation water that have been used in determining its quality are: (i) electrical conductivity (EC), (ii) sodium adsorption ratio (SAR), (iii) residual sodium carbonate (RSC), (iv) integrated effect of two properties, EC and SAR as well as SAR and RSC, and (v) specific ions which may cause toxic effects to plant growth.

2.4.1 Criteria and water quality classification

The earlier proposals of Eaton (1935), Scofield (1936), Wilcox (1948) and Magistad (1945) were similar as to the upper limit of the total salt concentrations, which was later proposed by USSL Staff (Richards, 1954) also. Eaton (1935), Scofield (1936) and Wilcox (1948) classified the irrigation water on the basis of total salt concentration and soluble sodium percentage. Keeping in view its behaviour with soil and plant, boron was also included as a factor for rating the suitability of water for irrigation (Scofield, 1936; Wilcox, 1948 and Magistad, 1945).

Kelley *et al*. (1940) suggested that the ratio of sodium to other cations (Ca and Mg), should not be exceed one for a good quality water. Similarly, Cassidy (1944) proposed index F (Figure of merit), calculated by the ratio of (Ca^{2+} + K^{+}) / (Na^{+} + K^{+}) in irrigation water. A value of 0.5 or less indicates good water.

U.S. Salinity Laboratory Staff (Richards, 1954) proposed a two way diagram for determining the suitability of waters for irrigation purposes on the basis of EC and SAR of water, which is widely used as it fairly takes into account both salinity and alkalinity hazards. In the diagram, the curve is given a negative slope to take into account the dependence of sodium hazard on total salt concentration. More important and adequate justification for the wide spread uses of SAR is its relative simplicity and the fact that it generally works (Bresler *et al.,* 1982).

Joshi (1956) used the pH and total salt concentration as criteria for judging the suitability of irrigation waters, but it is of limited use. Doneen (1962) introduced a new concept of effective salinity by taking total concentration of chloride and half that of sulphate ions instead of the total salt concentration.

The U.S. Salinity Laboratory Staff (Richards, 1954) classification was modified by Durand (1955) in Algeria; Kanwar (1961) and Ramamoorthy (1964) in India. Keeping in view the presence of high salt content in well waters and their tolerance to crops, Kanwar (1961) added one more class C_5 categorizing the water having EC from 5000 to 20000 μmhos cm^{-1}. His scheme included EC, SAR, soil texture and salt tolerance characteristics of the crops to be grown. Ramamoorthy (1964) suggested an another scheme also including these factors, he has not only extended the limit of C_4 class of salinity hazard to 6750 μmhos cm^{-1} but suggested an additional class of salinity hazard, C_5 having EC 6750 to 20250 μmhos cm^{-1}, keeping the same geometric relationship.

The importance of bicarbonate ion concentration in irrigation water as a quality determining factor was realised by Eaton (1950) who reported the adverse effect of waters containing HCO_3^- in excess of divalent cations. The excess carbonate and bicarbonate ions over Ca^{2+} + Mg^{2+} was designated as RSC and defined as (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}), concentration of each ion was expressed in me l^{-1}. Waters with values less than 1.25 RSC can be used safely, while, those with 1.25 to 2.50 were marginal and waters having values above 2.50 should be avoided. Several scientists (Agarwal *et al.*, 1956; Bower and Massland, l963; Singh and Sharma, 1970; Paliwal and Yadav, 1976; Nath and Chawla, 1980) have reported that critical limit of RSC as decided by Wilcox *et al.* (1954) do not hold good under field conditions and further that waters containing RSC upto 5 me l^{-1} have been used successfully. Gupta (1980) pointed out that irrigation with waters containing RSC as high as 10 me l^{-1} can be practiced without any problem for growing wheat on sandy loam calcareous soils, provided the SAR is less then 10, in areas where rainfall of 650-750 mm occurs.

2.4.2 Water quality indices

Ayers and Westcot (1976) while describing water quality evaluation stated that quality should infer how well a water supply fulfills the needs of the users and must be evaluated on the basis of its suitability for the intended use.

Water used for irrigation always contains measurable quantities of dissolved substances, which as a general collective term are called salts. These include relatively small but important amounts of dissolved solids originating from dissolution or weathering of the rocks and soil and dissolving of lime, gypsum and other salt sources as water passes over or percolates through them. The amount and kind of salts present will determine the suitability of water for irrigation. With poor quality water, different soil and cropping problems can be expected to develop special management practices to maintain full crop productivity.

Further, the problem that results from using poor quality water will vary both as to kind and degree but the most common ones are:

(A) Salinity: If excessive quantities of soluble salts accumulate in the root zone, the crop has extra difficulty in extracting enough water from the salty soil solution. This reduced water uptake by the plant which can result in slow or reduced growth.

(**B) Permeability:** The poor soil permeability makes it more difficult to supply the crop with water and may greatly add to cropping difficulties through crusting of seed beds, water logging of surface soil and accompanying diseases, salinity, weed, oxygen and nutritional problems. It is evaluated:

1. From total salts in the water since low salt water can result in poor soil permeability due to the tremendous capacity of pure water to dissolve and remove calcium and other solubles from the soil and,

2. From a comparison of the relative content of sodium to calcium and magnesium in the water. Furthermore, carbonate and bicarbonates can also affect soil permeability. But in many cases the evaluation of the sodium influence alone has proven to be in error basically because the interaction of three factors determines water's long-term influence on soil permeability. These factors are (i) sodium content relative to calcium and magnesium, (ii) bicarbonate and carbonate content, and (iii) the total salt concentration of the water. Ayers and Westcot (1976) have suggested that the quality of water can be assessed more precisely from the adjusted "SAR" in place of SAR and RSC as the former account for the integrated effect of the later. The adj. SAR can be computed as:

$$\text{adj. SAR} = \frac{Na}{\sqrt{(Ca+Mg)/2}} \quad [l+(8.4-pH_c)]$$

where, Na, Ca, Mg are in me l^{-1} from the water analysis and pH_c is calculated using the table values as suggested by Ayers and Westcot (1976), which related to the concentration values from the water analysis. The table values are then substituted in the pH_c equation:

$pH_c = (pK'_2 — pK'_c) + p\,(Ca + Mg) + p\,(Alk)$

$(pK'_2 — pK'_c)$ is obtained from using the sum of Ca + Mg + Na in me l^{-1}

p (Ca+Mg) is obtained from using the sum of Ca+Mg in me l^{-1}.

p (Alk) is obtained from using the sum of $CO_3^{2-} + HCO_3^-$ in me l^{-1}.

(C) Toxicity: A toxicity problem occurs when constituents in the water are taken up by the crop and accumulate in amounts that result in a reduced yield. This is usually related to one or more specific ion in the water namely boron, sodium and chloride.

(D) Miscellaneous: Various other problems related to irrigation water quality occur with sufficient frequency that they should be specifically noted. These include excessive vegetation growth, lodging and delayed crop maturity resulting from excessive nitrogen in the water supply, white deposits on fruit or leaves due to sprinkler irrigation with high bicarbonate water and suspected abnormalities indicated by an unusual pH of the water.

Based on the problem of salinity, permeability, specific ion toxicity and miscellaneous effects, Ayers and Westcot (1976) have suggested guidelines for the interpretation of water quality for irrigation. These guidelines are practical and usable in general irrigated agriculture for evaluation of the more common constituents in surface waters, under ground waters, drainage waters and sewage effluents.

2.4.3 Quality of irrigation water in India with special reference to Rajasthan

In India the main source of irrigation are rivers, canal, tanks, lakes and wells etc. The quality of Indian water resources has been reviewed and discussed in detail by Paliwal (1972, 1973), who classified the water quality of the country into three main groups, *viz.*, (i) water quality of arid and semi-arid regions having rainfall below 45 cm per annum, consisting of Gujarat, Rajasthan, northwestern parts of U.P. comprising Agra and Mathura districts adjoining to Rajasthan, Ferozepur, Bhatinda and Sangrur districts of Punjab and Rohtak, Gurgaon, Mohindergarh and Hisar districts of Haryana; (ii) water quality influenced by hydrological conditions i.e. high water table and water logging, consisting of some of the areas of Punjab, Haryana, Delhi and U.P. in canal irrigated areas and river basins, and (iii) water quality of wells in some areas of coastal regions as influenced by sea water intrusion and inundation in the states of West Bengal, Orissa, A.P., T.N., Kerala, Maharastra and Gujarat. Further, it was expressed that after canal the important source of irrigation is well water and the quality of well water assumes greater importance because of its high variability due to climatological and hydrological conditions. Manchanda *et al.* (1989) reported that in Haryana 55 per cent samples of ground water were of poor quality. The problem of poor quality ground water has also been reported in many parts of other states namely, Punjab, Gujarat, U.P., M.P., and in the coastal regions.

In Rajasthan well waters form an important source of irrigation, where 60 per cent of the total irrigated areas is covered by wells only and the quality of these well water is highly variable. Paliwal (1972) reviewed the water quality of ground water resources of entire state on the basis of the data available and it was concluded that 54 per cent waters are highly saline having EC above 2250 μmhos cm^{-1}, out of this 28.4 per cent waters show EC value above 5000 μmhos cm^{-1}. The salinity and sodium hazards from well waters are more in the western region where aridity is more and decrease with the increase of rainfall in the east. In arid and semi-arid regions, ground water is generally saline or contains high RSC. Nearly 84 % of the area in arid Rajasthan has ground water having salinity over 2.2 dS m^{-1} EC constituting 60 % of the ground water sources (Joshi and Jain, 1993).

Shankarnarayana *et al.* (1965) reported that the waters of Jodhpur and Pali districts are very high in EC, SAR and chloride content, while that of Bhilwara, Ajmer and Bharatpur are moderate to highly saline in nature with dominance of sodium salt (Mathur *et al.*, 1968). Most of the well waters of Chambal Command Area of Kota and Bundi were medium to highly saline (Mehta and Talati, 1958 and Talati and Mehta, 1959), whereas, in Nagaur district most of the well waters were found to be highly saline having sodium as the dominant cation with high RSC values (Paliwal and Gandhi, 1969). The well waters of Jobner fall in the medium salinity class (Singh *et al.* 1967). The well waters of Bhilwara have high salinity and are dominated with chloride and sodium ions and are of Na^+ - Ca^{++} - Mg^{++} type as cations and Cl^- - HCO_3^- - SO_4^+ as anions (Ram Deo, 1973).

The application of SAR to the group of water, which have EC higher than 5 dSm^{-1} and Mg/Ca ratio higher than 1 is obviously questionable. The SAR value of these types of irrigation water was not correlated with the ESP of irrigated soil with this water. Therefore, Gupta (1984) suggested that SAR of saline irrigation waters, which have high Mg/Ca ratio, should be calculated simply as $Na/\sqrt{Ca}$ and designated the indices as sodium to calcium activity ratio.

Dhir (1977) has reported for groundwater of arid Rajasthan that water having EC above 2.25 dSm^{-1} invariably have SAR more than 10, while, at higher salinity the values of SAR are mostly above 26. It is evident from the review reported above that the majority of well waters in Rajasthan are poor in quality with respect to salinity and sodium hazards but little attention has been made towards the bicarbonate concentration which is reported to be very high (Paliwal, 1973) and forms about 60.0 and 31.0 per cent of the total salt concentration in the well waters having EC value in the range of 0 to 2000 and 2000 to 6000 μmhos/cm, respectively, however, at higher salinity range it forms 10 to 12.5 per cent only. Thus, HCO_3^- concentration forms an important water quality determining factor in the low and moderately saline irrigation water.

Fluorine stimulates the growth of many plant species (Baumeister and Burghardt, 1957) and proves toxic when present beyond certain critical limits, applied either through irrigation water or fertilizers (Brennan *et al.,* 1950). But the role of fluorine as a trace element in plant nutrition is not yet well established, though, undoubtedly it affects human and animal health. Symptoms of dental and skeletal disorders in Punjab and A.P. owing to excess of fluorine in drinking and irrigation water were reported by Pandit *et al.* (1940), Day (1940), Khan and Wig (1945), Singh *et al.* (1962) and Ramamohan Rao and Bhaskaran (1964). The continuous use of irrigation water carrying high concentration of fluorine may lead to its accumulation beyond the critical limits and affect the quality of crop because most of the applied fluorine is retained on the surface (Specht and MacIntire, 1961) and is not leached down even in a considerable period (MacIntire, 1957). Kanwar and Mehta (1968) reported toxic concentration of fluorine content in irrigation water of Hisar and Sangrur districts of Haryana and Punjab, respectively. Some of these waters are unsuitable even for drinking and may prove injurious to the quality of fodder and consequently to cattle. Further, Paliwal *et al.,* (1969) deals with fluorine content of the well waters of Bhilwara districts of Rajasthan and its relationship with other indices of quality of irrigation water. The following were the main conclusion, (i) fluorine content of 118 water samples varied front 2.1 to 24 ppm; (ii) these water samples were unsuitable for drinking and may create health hazards; (iii) fluorine content significantly correlated with the EC, SAR and boron content of these well waters, and (iv) fluorine content of irrigation waters should also be considered while determining the quality of irrigation waters.

2.5 MANAGEMENT ALTERNATIVES

The demand for the land is increasing at a very fast pace. It is only the agriculturally productive lands, which are being diverted to meet the demands for various purposes (Industry and domocile etc.). Therefore, an attempt should be made to bring those lands under cultivation which till now are considered as unproductive notably salt-affected lands to increase agricultural production. Plant growth can be restricted or entirely prevented by increased levels of salinity and/or alkalinity in the soils. These soils have to be reclaimed so that they become productive for which the processes of accumulation of salts and build up of ESP have to be reversed. To achieve these objectives provision of adequate drainage, replacement of Na^+ ions from the soil-exchange complex and leaching out of soluble salts below root zone have to be ensured.

Systematic planning for reclamation work requires characterization of the problem (e.g. extent and kind of salinity or alkalinity/sodicity) as the first step. Thereafter, for each specific problem (salinity and sodicity), specific systems of management have to be followed (Totawat and Somani, 2002). The following management alternatives are suggested to harvest a bounty of crop on salt-affected soils.

2.5.1 Land Development

Land development for salt-affected soils involves cleaning of unused land to make it fit for cultivation and allowed improved and efficient water management and unrestricted drainage. Levelling of undulating topography prior to amelioration is a pre-requisite to ascertain uniform leaching of salts (Na_2SO_4) released as a consequence of amelioration. Optimum slope needs to be selected depending upon soil texture and irrigation method. The maximum permissible longitudinal slope for sand, clay and loam is 0.25, 2.50 and 6.25 per cent, respectively (Gupta and Gupta, 1987). A higher uniformity of levelling ensures uniform leaching and higher crop production (Somani and Totawat, 1993).

2.5.2 Deep Tillage

It is known that salts tend to accumulate closer to the soil surface in unirrigated drylands, which could be move downward with reclamation, cultural manipulation and irrigation. Hence, deep ploughing and sub-soiling operation will loosen the dense sub-soil and will hasten the leaching of soluble salts including displaced sodium of sodic soil under reclamation phase. It can also lead to auto-reclamation if there is a gypsic horizon just below a sodic horizon (Somani and Totawat, 1993).

2.5.3 Hydro-technical Management

The reclamation of salt-affected soils by this method involves the removal of salts from the saline soil or displacement of sodium ions from the exchange complex of alkali soils through the processes of leaching with water and drainage.

Gupta and Abichandani (1970) reported that in the highly calcareous alkali soils, the high ESP was reduced from 59.5 to 18.0 and from 34.9 to 11.0 alone due to leaching caused by the rainfall (350 to 450 mm) in Western Rajasthan. ECe in the top 0-20 cm layer decreased from 11.8 to 2.6 and 22.2 to 2.1 dS m^{-1} in two soils, respectively.

Alkali soils do not disperse unless the electrolyte concentration is low. The usual process involving application of calcium supplying amendment followed by leaching may fail or is so slow that it may not be economically feasible, mainly because of the extremely low permeability of alkali soil to the usual low electrolyte irrigation waters. The infiltration of water into alkali soil can, however, be improved by increasing the electrolyte concentration of soil solution. The high – salt – water – dilution (HSWD) technique makes use of highly saline water divalent to total cation content ratio of 0.3 and above, in successive dilution is a promising method for reclaiming alkali soils with low permeability. Even poor quality water could be used after neutralizing its alkali character and by improving its divalent cation concentration using H_2SO_4, gypsum and $CaCl_2$ etc. (Somani and Totawat, 1993).

The leaching of the salt-affected soils leads to highly saline drainage water. Therefore, suitable measures for its disposal should be taken before initiating the leaching processes, particularly in areas having high water table. It is important to check the re-salinisation or re-alkalisation of the soils. Thus, provision of adequate drainage system is a pre-requisite for any reclamation process. (Totawat and Somani, 2002).

2.5.4 Chemical Amelioration

Reclamation of sodic soils requires neutralization of alkalinity and replacement of the sodium ions from the soil-exchange complex by the more favorable calcium ions. This can be accomplished by the application of chemical amendments (the material that directly or indirectly furnish divalent cations, usually Ca^{2+} for the replacement of sodium from the exchange complex of the soil) followed by leaching to remove soluble salts and other reaction products. Among chemical amendments calcium chloride, sulphur, iron sulphate, sulfuric acid, pyrites and gypsum are ones which can be used for reclamation of alkali soils (Somani and Totawat, 1993). While taking up reclamation, the choice of amendment is governed by many considerations. The major of which physico-chemical properties of the soil, desired rate of replacement of sodium ions, availability and economic considerations. Gypsum, a natural sulphate of calcium, is a well accepted amendment for alkali amelioration. However, looking to its very low solubility (0.25%), particularly in calcareous sodic soils, acid and acid former amendments (sulphur, sulphuric acid and pyrites) could be a good alternatives (Mehta *et al.*, 1969; Agarwal *et al*., 1976; Dargan *et al*., 1982 and Gupta *et at.*, 1995).

For these purpose pyrite as well as commercial sulphuric acid may be used to reduce the toxicity of sodium ions and amelioration of these soils (Somani and Totawat, 1998).

2.5.5 Biological Amelioration

Organic materials and the action of plant roots improve biological activity in the soil. The decomposition of materials increases the concentration of CO_2 and organic acids in the soil which help in mobilizing calcium by dissolving calcium compounds. This can be accomplished by green manuring (dhaincha), incorporation of crop residues, application of FYM, pressmud, spentwash and other organic materials (Bajwa, 2002).

2.5.6 Crop Selection

Crops differ considerably in their ability to tolerate salinity/sodicity. The intergenic differences can be exploited for selecting the crop that gives satisfactory yields under adverse situations. Thus, crops, which are tolerant to salinity/sodicity, should be preferred in early phase of reclamation. Rice is a well suited crop during reclamation of sodic soil. It can tolerate ESP of soil upto 55 (Abrol and Bhumbla, 1979).

Barley is another potential crop, which could be grown in the initial stage of reclamation, in particular, in saline environment, while, wheat is a most promising crop for *rabi* on sodic soil under reclamation. (Milap Chand *et al.*, 1977 and Somani and Totawat, 1993).

Dhaincha *(Sesbania aculeata)* is considered to be the best green manure crop on sodic soil under reclamation. Taking a green manure crop of dhaincha accelerate the process of reclamation since it posses highest Ca (34.3 % CaO on ash basis) and is tolerant to sodicity (ESP upto 45) and water logging. Its extensive root system, easy rotability, more acidic cell sap and luxuriant growth under adverse conditions further adds to its suitability (Somani and Totawat, 1993).

2.5.7 Crop Rotation

A best crop rotation is one which not only provides good returns but also help to control sodicity in the growing media. Growing of crops like rice, berseem and dhaincha results into build up of exchangeable calcium on the exchange complex of the soil, an essential requirement of alkali amelioration (Totawat and Somani, 2002). The order of superiority in alkali amelioration action through increased Ca/Na ratio in soil under different crops is berseem > rice > dhaincha > alfalfa > clover (Somani and Totawat, 1993). Kanwar (1969) suggested inclusion of sugarbeet in crop rotation. Paddy – berseem/ barley or paddy – wheat – dhaincha rotations are more remunerative in the early phase of reclamation of highly sodic soil having pH above 10.5 (Dargan, 1979).

2.5.8 Sowing / Planting Practices

Appropriate adjustment in planting techniques can provide a congenial environment in soil around the germinating seed. This can be achieved by judicious selection of planting practices, seed bed shaping and irrigation management. Since germination and early seedling stages are very sensitive to salt injury, it is advisable to raise the seedlings in low saline beds and after certain amount of adaptation, they should be transplanted to the actual more saline fields. Dargan and Chillar (1973), reported that in highly sodic soils, sowing the seed on one side of the ridge half way between top and bottom opposite to the sun direction gave significantly higher yield than that of flat sowing, alternate ridge sowing, transplanting on the surface and transplanting on ridge. If salinity is a problem, planting seeds in the centre of a single row raised bed will place the seed/seedling exactly in the area where salt is expected to concentrate. A double row raised planting bed may be comparatively advantageous (Totawat and Somani, 2002).

3. MATERIALS AND METHODS

A research investigation entitled "Characterization of salt-affected soils and water resources of sub-humid southern plains of Rajasthan" was undertaken in district Chittorgarh to understand the nature and distribution of salt-affected soils and suggest the management practices to be followed and develop suitable land use plan for such areas.

The details of the materials used and techniques adopted during the course of investigation are presented in this chapter.

3.1 Description of study area

The district Chittorgarh is situated between 23^{o}32' and 25^{o}13' north latitude and 74^{o}12' and 75^{o}49' east longitude in the south eastern part of Rajasthan. It is bounded on the north by Bhilwara and Bundi district; in the east by Kota district and the state of Madhya Pradesh; on the south by Madhya Pradesh state; on the north west by Rajsamand district and on the west by Udaipur and Banswara district, respectively. Administratively, there are thirteen tehsils, *viz.* Rashmi, Gangrar, Begun, Bhainsrorgarh, Chittorgarh, Kapasin, Dungla, Bhadesar, Nimbahera, Chhoti Sadri, Bari Sadri, Pratapgarh and Arnod. The study area and location of pedons are depicted in fig. 3.1.

3.1.1 Geology

The area is almost entirely underlined by Precambrian rocks (Sehgal, 1975 and Krishnan, 1982). Some characteristics of Precambrian rocks and their classifications are given here under:

(A) Banded gneissic complex: It covers quite an extensive area of the district and this group comprises gneisses, schists and irregular assemblages of intrusive rocks. Wide variability of texture and general lack of consistency in their composition characterizes the banded gneisses. This rock is medium to coarse grained and is composed of translucent quartz and pink feldspar with varying amount of biotite.

(B) Aravalli system: The Aravalli series play an important role in the rock formation of the district. The Bundelkhand gneisses are successively overlined by Aravalli system. The western part of the district exposes the oldest rocks comprising of slates, phyllites, mica schists with intercalated bands of dolomite, quartzite and migmaties belonging to the pre-Aravalli period dating back to over 2,500 million years. These are succeeded by limestones, which are generally argillaceous and dolomitic in composition. The Berach granite has intruded the pre-Aravalli rocks. These were later eroded and leveled before the sedimentation of the Vindhyan rocks commenced about 1,400 million years ago under shallow water conditions preceded by volcanic activity as evidenced by the andestic lavaflows in the Kharmalia area.

(C) Delhi system: The Aravalli system is succeeded by isolated outliners comprising of conglomerates grading upwards into massive quartzites, occurring in the midst of the Aravalli schists and gneisses.

(D) Raialo series: The raialo series is present in some parts of the district. It comprised of biotite schist (garnet and staurolite bearing limestone), raialo marble and quartzite.

(E) Vindhyans: In addition to the formations of rocks described above, there are rocks of Vindhyan system with a well marked unconformity. The Vindhyan rocks include sandstones, gritsporcellanites, limestone and shales. The limestone at places shows evidence of algal life in the form of arch shaped structure known as 'stromatolite'. In the north eastern part the Vindhyan formation are truncated by the Great Boundary Fault. In the southern part of the district, especially in the area around Pratapgarh, the pre-Aravalli and Vindhyan rocks are overlain by basaltic flows, which form flat topped hills. It is thought that the lava poured out of several fissures in the earth's crust under a supper heated condition spread out far and wide as horizontal layers about 65 million years ago.

3.1.2 Physiography

The topography of the district is generally undulating but hills belonging to the famous Aravalli range are scattered all over the area. The western, southern and northern parts of the district are to some extent plain. Bhainsrorgarh area in the east is practically hilly leaving aside some portion, which is plain but is surrounded by hills. The slopes of the hills are gentle as well as steep and are wooded. The rivers that flow through the district are Banas, Berach, Chambal and Jakham, while, Wagan, Gambhiri, Bamani (Brahmani) and Gunjali are their tributaries. The district is devoid of any natural or artificial lake. The district gently slopes from south to north, the height varying from 317 metres to maximum 617 metres (Palkhera) above mean sea level.

3.1.3 Climate

Climate influences soil formation mainly through precipitation and temperature. The climate of the study area is semi-arid characterized by extremes of temperature and low wind velocity. The district has a hot dry summer and a bracing cold season. The cold season is from December to February and is followed by the hot season from March to about the third week of June. The south west monsoon season which follows thereafter last till about the middle of September.

(A) Precipitation: The annual normal rainfall of Chittorgarh district is 852.1 mm and is quite erratic (Table 3.1). More than 80 per cent of the annual rainfall is received during the monsoon season from July to August, which are the rainiest months. Pre-monsoon rains however, starts towards the end of June and monsoon continues till the first week of October (Sehgal, 1975).

The normal rainy days in the district are about 34 a year. This number varies from 28 at Kapasin to 41 at Pratapgarh.

(B) Temperature: The mean annual temperature is 22.0°C. The hottest month is May (40°C) while the coldest month is January (4°C). Cold waves in the wake of western disturbances pass across north India. The minimum temperature sometimes drops to –1 to 1°C. Both days and night temperature increases rapidly from March to May. There is an appreciable drop in temperature with advance of south west monsoon by the end of June. The soil temperature regime is hyperthermic.

The water balance diagram (Fig. 3.2) shows that precipitation is greater than PET during the month of July to September, whereas PET exceeds rainfall in most of the other months. Since moist period is more than 90 days, this area is classified under ustic soil moisture regime and the length of growing period (LGP) of the district varies between 90 to 110 days. The climatic classification of the district is ‘semi-arid (dry), small or no seasonal water surplus, hyperthermic, a summer concentric type (Mandal *et al.*, 1999).

3.1.4 Natural vegetation:

Vegetation is an important factor and plays a vital role in soil formation. Its influence can be noted in the area where dense forest and pasture exist (Buol *et al.*, 1998). About 14.31 per cent of the total reporting area of the district was under forest during 1998-99. The forest area in this district has been categorized as ‘Reserved’, ‘Protected’ and ‘Unclassified’. It is also well known that vegetation minimizes soil erosion. Man has modified the natural vegetation of the area. Since the study area is on the eastern side of the Aravalli, the average rainfall is higher and hence the natural cover is substantial. The forest can be categorized as dry tropical deciduous (Anonymous, 1975) and xerophytic type. The details about common vegetation of the area given in table 3.2.

Table 3.2 The common vegetation of district Chittorgarh

Common name	Botanical name	Common name	Botanical name
Dhokra	**Anogeissus pendula**	Mahua	*Bassialan latifolia*
Babul	*Acacia arabica*	Bahera	*Terminalla bellerica*
Gular	*Ficus glomerata*	Khair	*Acacia catechu*
Khejri	*Prosopis spicigera*	Karanj	*Pongamia pinnata*
Bans	*Dendrocalamus strictus*	Dhak	*Butea frondosa*
Palash	*Butea monosperma*	Bargad	**Ficus bengalensis**
Neem	*Azadirachta indica*	Amla	*Phyllanthus emblica*
Sesam	*Delbargia sissoo*	Khajur	*Phoenix dactylifera*
Tendu	*Disophyros molamoxylon*	Zharberi	*Zizypus nummularia*
Pipal	**Ficus religiosa**	Salar	*Banswellae spp.*

3.1.5 Surface drainage

Chittorgarh district is drained by the rivers namely Banas, Berach, Chambal and Jakham, while, Wagan, Gambhiri, Bamani (Brahmani) and Gunjali are their tributaries. The general slope of the district is from South to North. The rivers and tributaries are mostly seasonal.

3.2 Present land use and agriculture

About 34.72 per cent of the area of the district is devoted to growing of various crops. Permanent pastures and other grazing land occupy another 7.69 per cent of the area. Fallow land constitutes 4.77 per cent, while, forests extend over 14.31 per cent of the total area. Culturable wasteland stands at 20.02 per cent of the area of the district. The rest of the 18.49 per cent is not available for cultivation, either because being barren (14.6 per cent) or has been put to non agricultural uses (3.89 per cent) such as, land under roads, buildings etc. (Anonymous, 2002).

Kharif and *rabi* are the main crops in the district. *Kharif* crops comprises maize, sorghum, cotton, pulses, groundnut, sugarcane and paddy, while the *rabi* crops consists of wheat, barley, gram, oilseeds, methi, alsi, coriander and opium. The third crop 'z*ayad*' is also grown where vegetables like brinjals, cucumbers and water and musk melons are raised in the river beds during the summers.

3.3 Delineation of salt-affected soils

An integrated approach of image interpretation coupled with field studies was followed to delineate the salt-affected soils of district Chittorgarh. Wasteland mapping in Chittorgarh district had been done toposheet wise on 1:50,000 scale. Out of various categories of wastelands, salt-affected land is one of the mapped category, which had been mapped on the basis of spectral reflectance. These coloured toposheet acquired from Regional Remote Sensing Agency, Jodhpur, which depict the salt-affected area in district Chittorgarh. Information on slope, land use, etc. for the study area were derived from the base-map of 1:50,000 scale Survey of India toposheet numbers $45^{I}/_{13}$, $45^{I}/_{14}$, $45^{K}/_{8}$, $45^{K}/_{16}$, $45^{L}/_{1}$ to $45^{L}/_{16}$ and $45^{0}/_{4}$. The boundaries of salt-affected soils were drawn and superimposed on the base map in the same scale. These delineated sites were verified by field traverse. To demarcate areas of similar soils, several auger holes and field checks were undertaken in each soil boundary and the observations for colour, texture, depth, etc. were recorded. On the basis of these observations representative pedon sites were selected (Fig. 3.1) for detail investigations.

3.4 Field and laboratory investigations

For a comprehensive pedogenic investigation, combined uses of field and laboratory parameters are essential. Field methods were employed for recording morphological features that developed in a soil system as a result of characteristic pedogenic processes. Laboratory determinations were useful not only for supporting field observations, but also for elucidating and evaluating the changes that have taken place or are occurring in a soil profile. In view of this field and laboratory methods are considered complementary to each other in pedogenic investigations. The field and laboratory methods followed in the present investigation are discussed here under**:**

3.4.1 Field investigation

(A) Pedon study: After delineating the sites, twenty representative pedons (1.5 m x 1.5 m x 1.0 m or Bed rock) were exposed in Kapasin (7), Rashmi (3), Dungla (7), Begun (2) and Pratapgarh (1) tehsils of Chittorgarh district (Fig.3.1).

(a) Excavation and description of pedon: Pedons were excavated at the selected sites and extended down to parent bed rock or weathered parent material or upto Ck horizon. Eastern wall of each profile was cut out vertically, while, the western side was dug out for easy approach. Morphological description, depth, colour, texture, structure, consistency, porosity, nodules, roots, effervescence with dilute HCl etc. were recorded according to the procedure described by Soil Survey Division Staff (1995). Soil-site characteristics such as slope, landform, geology, parent material, erosion, runoff, elevation, natural vegetation, land use and related data were also noted down.

(b) Collection of soil samples: Two kilograms of soil sample was collected in cotton bags from each depth at an interval of 15 cm of the pedons under study and labelled properly. In all 118 soil samples (4 to 6 samples from each pedon depending upon the depth of bed rock/weathered parent rock) were collected from the 20 profiles dug for the proposed study.

(B) Ground truth: Ground truth were also collected from surface layers (0-15 cm) from other fields of the study area by using area delineated under satellite imageries (purposive sampling). In all 71 ground truths were collected to establish correlation with the soils of pedon, if any.

3.4.2 Laboratory investigation

(A) Preparation of soil samples: Soil samples collected were air-dried. Dried samples were gently crushed with a wooden roller and passed through 2 mm sieve. Sieved soil samples (< 2 mm) were stored in 1 kg capped plastic wares for laboratory analysis.

(B) Soil analysis: Physical and chemical properties of the soils were determined following standard methods as out lined in table 3.3.

Table 3.3 Methods employed for the determination of different soil properties

Soil parameter for analysis	Method	Reference
(a) Physical properties		
Bulk density	Clod method (Wax mixture)	Page *et al.* (1982)
Particle density	Pycnometer method	Richards (1954)
Porosity	Computation	Richards (1954)
Mechanical analysis	International Pipette method	Piper (1950)
Water retention characteristic	Pressure Plate apparatus	Richards (1954)
Plant available water capacity (PAWC)	Computation	Gardner *et al.* (1984)
PAWC = Plant available water — (Gravimetric water content at 0.03 MPa — Gravimetric water content at 1.5 MPa) x B.D. x horizon thickness		
(b) Chemical properties		
pH	Using saturation paste extract (pH meter)	Richards (1954)
Electrical conductivity	Using saturation paste extract (Solubridge)	Richards (1954)
Organic carbon	Wet digestion method	Walkley and Black (1934)
Calcium carbonate	Acid neutralization	Allison and Moddie (1965)
Gypsum requirement	Using saturated gypsum solution and versenate titration.	Schoonover (1952)
Soluble ions (in saturation extract):		
Sodium and Potassium	Flame photometery	Richards (1954)
Calcium and Magnesium	Versenate titration	Richards (1954)
Chloride	Silver nitrate titration	Richards (1954)
Carbonate and bicarbonate	Acid neutralization	Richards (1954)
Sodium adsorption ratio	Computation	Richards (1954)
Exchangeable ions		
Cation exchange capacity	Neutral normal sodium acetate saturation	Richards (1954)
Calcium and Magnesium	Neutral normal sodium acetate extractant and versenate titration	Richards (1954)
Sodium and Potassium	Neutral normal ammonium acetate extractant and flame photometery	Richards (1954)
Exchangeable sodium percentage	Computation	Richards (1954)
(C) Available nutrient status		
Nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Phosphorus	0.5 M $NaHCO_3$ extractant of Olsen's blue colour method	Olsen *et al.* (1954)
Potassium	Neutral normal ammonium acetate extraction method	Richards (1954)
Micronutrients (Cations)	DTPA extract	Lindsay and Norvell (1978)

3.5 Categorization of salt-affected soils

(A) Salinity hazards: The EC of saturation extract is the standard measure of salinity. The special advantage of the saturation extract method of measuring salinity lies in the fact that the saturation percentage is directly related to the field moisture range. The following classes of salinity as proposed by Soil Survey Division Staff (1995) were used in categorizing the salinity hazards.

Class	**ECe (dS m^{-1})**
Non saline (S_1)	< 2
Very slightly saline (S_2)	2 — 4
Slightly saline (S_3)	4 — 8
Moderately saline (S_4)	8 — 16
Strongly saline (S_5)	> 16

(B) Sodicity hazards: Alkali soils are those salt-affected soils, which are predominated with salts capable of alkaline hydrolysis, *viz.*, sodium carbonate, sodium bicarbonate and sodium silicate. Many a time the existence of sodium carbonate in saturation extract goes unnoticed because the dissolved carbonates react with calcium and precipitated as $CaCO_3$. Calcareous soils having paste pH > 8.2 and Na/Cl ratio > 1.0 indicate the presence of sodium carbonate. Abrol *et al.* (1980) and Gupta *et al.* (1981) have used exchangeable sodium percentage (ESP) of > 15 and pH and EC of saturation paste in water more than 8.2 and less than 4 dSm^{-1}, respectively to categorize a soil to be sodic. The criteria adopted for grouping soils in various sodicity classes (Abrol *et al.*, 1988 and modified by Saxena and Verma, 1995) are given here under:

Sodicity class	**ESP**
None to slight	< 15
Light to moderate	15 — 30
Moderate to high	30 — 50
High to very high	> 50

3.6 Ground water quality

Underground water samples from forty six existing well/tube wells in the area under study were also collected for laboratory analysis in 1 litre plastic bottles and labeled for maintaining proper records.

3.6.1 Water analysis

Different methods of analysis used to determine various parameters of well/tube well water are enlisted in table 3.4.

Table 3.4 Methods employed for the determination of different characteristics of ground water

Item of analysis	Method	Reference
pH	pH meter	Richards (1954)
Electrical conductivity	Solubridge	Richards (1954)
Soluble ions		
Sodium and Potassium	Flame photometery	Richards (1954)
Calcium and Magnesium	Versenate titration	Richards (1954)
Chloride	Silver nitrate titration	Richards (1954)
Carbonate and bicarbonate	Acid neutralization	Richards (1954)
Sulphate	Rapid titrimetric and turbidity method	Jackson (1979)
Fluoride	Ion specific electrode	McQuaker and Gurney (1977)
Boron	Colorimetric using carmine	Richards (1954)
RSC	Computation	Richards (1954)
Adj. SAR	Computation	Ayres and Westcot (1976)

3.6.2 Water quality evaluation

The well/tube well waters were categorised for their salinity classes and discussed in the light of guidelines suggested by Ayers and Westcot (1976) (Table 3.5). National Academy of Sciences and National Academy of Engineering (1972) were suggested guidelines regarding fluoride content i.e. 1 mg l^{-1} can safely used for continuous irrigation but beyond 2 mg l^{-1} is having toxic effects from the view of drinking purpose for human beings and livestock. These guidelines are practical and usable, in general, for irrigated agriculture. The water quality guidelines suggested are intended to cover a wide range of conditions in irrigated agriculture and incorporate the newer concept in expressing the soil-water-plant relationship.

3.7 Soil site suitability for land use planning

Land suitability classification refers to the fitness of a given type of land for a defined use (Sys *et al.*, 1991). The categories recognized in land suitability classification are order, classes, sub classes and unit. There are two orders suitable (S) and non-suitable (N). The classes distinguished under order suitable (S) are S_1 — highly suitable; S_2 — moderately suitable, and S_3 — marginally suitable and under order non suitable (N) are N_1 – actually unsuitable but potentially suitable and N_2 – actually and potentially unsuitable. The sub classes reflect kinds of limitation as in land capability sub classes (FAO, 1976). The suitability units in a sub class differ in management requirements. Depending upon the purpose, scale and intensity of study, either all or limited number of categories may be adopted. Soil suitability models FAO (1976) and Sys *et al.* (1991) for specific crop are dependent upon the suitability criteria of soil site characteristics under the existing management conditions.

Soil site suitability criteria (Sys *et al.*, 1991) with slight modification (NBSS & LUP, 1994 and 1998) were matched with soil site characteristics of different soil types to arrive at suitability class. The criteria's are presented in Appendix I.

3.8 Soil sustainability

It is based on evaluating the constraints of soils which are accomplished by using scoring method, as outlined by Lal (1994), who has proposed a method for evaluating soil sustainability based on soil indicators. The method provides a fair understanding of constraints in achieving the goal of soil sustainability. To sustain the crop production on soil it is necessary to make a balance between soil quality and constraints while raising crops.

Table 3.5 Guidelines for interpretation of water quality for irrigation

Irrigation problem	Degree of problem		
	No problem	Increasing problem	Severe problem
A. Salinity (affect crop water availability)			
EC_w (dS m^{-1})	< 0.75	0.75-3.0	> 3.0
B. Permeability (affect infiltration rate into soil)			
EC_w (dS m^{-1})	> 0.5	0.5-0.2	< 0.2
adj. SAR			
Montmorillonite. (2:1 type)	< 6	6-9 [1]	> 9
Illite-vermiculite (2:1 type)	< 8	8-16 [1]	> 16
Kaolinite-sesquioxide (1:1 type)	< 16	16-24 [1]	> 24
Mixed mineralogy*	< 10	10-16 [1]	> 16
C. Specific ion toxicity (affects sensitive crops)			
Sodium (adj. SAR)	< 3	3-9 [1]	> 9
Chloride (me l^{-1})	< 4	4-10 [1]	> 10
Boron (mg l^{-1})	< 0.75	0.75-2.0 [1]	> 2.0
D. Miscellaneous effects (affects susceptible crops)			
$NO_3 – N$ or $NH_4 – N$ (mg l^{-1})	< 5	5-30 [1]	> 30
HCO_3 (me l^{-1})	< 1.5	1.5-8.5 [1]	> 8.5
pH		(Normal range 6.5-8.4)	

* Computing the average values.

[1] Use lower range if $EC_w < 0.4$ dS m^{-1}

Use intermediate range if $EC_w = 0.4\text{-}1.6$ dS m^{-1}

Use upper limit if $EC_w > 1.6$ dS m^{-1} **Source:** Ayers and Westcot (1976)

Table 3.1 Normal and extreme of rainfall in district Chittorgarh

Station	No. of years of data		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Highest annual rainfall as % of normal & year**	Lowest annual rainfall as % of normal & year**	Heaviest rainfall in 24 hours*	
																		Amount (mm)	Date
Chittorgarh	9	a	9.1	2.5	4.3	1.8	8.9	76.2	370.8	374.7	138.7	9.1	7.1	5.6	1008.8	152	55	274.3	20.07.1943
		b	0.6	0.3	0.2	0.2	0.7	2.9	11.7	10.7	5.4	0.3	0.3	0.2	33.5	(1944)	(1949)		
Pratap-garh	50	a	4.1	3.8	3.3	1.3	9.9	109.0	301.7	290.6	151.4	20.8	9.7	3.3	908.9	197	42	279.9	05.09.1955
		b	0.4	0.4	0.3	0.2	1.0	5.1	13.1	12.2	6.6	1.0	0.6	0.3	41.2	(1917)	(1911)		
Kapasin	9	a	5.6	2.0	0.0	0.0	0.8	77.5	269.2	317.5	98.8	1.3	4.1	4.8	781.6	196	56	254.0	21.08.1944
		b	0.3	0.2	0.0	0.0	0.1	3.7	10.4	9.2	3.9	0.1	0.1	0.1	28.1	(1944)	(1949)		
Nimbahera	20	a	5.1	1.0	1.8	3.1	2.3	79.3	338.0	253.5	111.0	8.6	4.3	1.5	709.5	189	40	222.6	08.09.1973
(Nizamat)		b	0.5	0.1	0.2	0.3	0.2	3.7	10.3	9.7	4.7	0.5	0.2	0.1	30.5	(1944)	(1949)		
Chittorgarh		a	6.0	2.3	2.3	1.5	5.5	85.5	294.9	309.1	125.0	9.9	6.3	3.8	852.1	211	44	--	--
(District)		b	0.5	0.3	0.2	0.2	0.5	3.9	11.4	10.5	5.1	0.5	0.3	0.2	33.6	(1917)	(1911)		

(a) Normal rainfall in mm (b) Average number of rainy days (days with rain of 2.5 mm or more)
* Based on all available data up to 1980. ** Years given in brackets.

Source: Anonymous (1988)

Table 4.1.4 Morphological description of pedon P_1

Location	:	74°13’ E, 24°51’ N
Village	:	Bhopalsagar (Mal)
Landform	:	Nearly level plain
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to single crop of barley

Depth (cm)	Morphological features
0-15	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structures; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate sub-angular blocky structure; friable, slightly sticky and non-plastic; common, medium roots; violent effervescence.
30-45	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate sub-angular blocky structure; friable, slightly sticky and non-plastic; violent effervescence.
45-60	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate sub-angular blocky structure; firm, sticky and slightly plastic; violent effervescence.
60-75	Dark brown (10 YR 3/3 M); clay loam; massive; firm, sticky and slightly plastic; violent effervescence.
75-90	Dark brown (10 YR 3/3 M); clay loam; massive; firm, sticky and slightly plastic; violent effervescence.

Table 4.1.5 Morphological description of pedon P_2

Location	:	74°10' E, 24°52' N
Village	:	Phalasiya
Land form	:	Gently sloppy plain
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to double crop of maize and wheat

Depth (cm)	**Morphological features**
0-15	Dark grayish brown (10 YR 4/2 M); sandy clay loam; massive; friable, non-sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); sandy clay loam; massive; friable, non-sticky and non-plastic; strong effervescence.
30-45	Dark grayish brown (10 YR 4/2 M); sandy clay loam; massive; friable, slightly sticky and plastic; violent effervescence.
45-60	Yellowish brown (10 YR 5/4 M); clay loam; massive; friable, slightly sticky and plastic; fine irregular calcareous nodules; violent effervescence.
60-75	Yellowish brown (10 YR 5/4 M); clay loam; massive; friable, slightly sticky and plastic; fine lime nodules; violent effervescence.
75-90	Yellowish brown (10 YR 5/4 M); clay loam; massive; friable, slightly sticky and plastic; fine lime nodules; violent effervescence.

Table 4.1.10 Morphological description of pedon P_3

Location	:	74°14’ E, 24°55’ N
Village	:	Kanakhera
Land form	:	Nearly level plain
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Pasture

Depth (cm)	Morphological features
0-15	Brown (10 YR 4/3 M); sandy clay loam; medium, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Brown (10 YR 4/3 M); sandy clay loam; medium, weak, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
30-45	Brown (10 YR 4/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
45-60	Brown (10 YR 4/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
60-75	Grayish brown (10 YR 5/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; white powdery lime; violent effervescence.
75-90	Grayish brown (10 YR 5/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.

Table 4.1.6 Morphological description of pedon P_4

Location	:	74°12’ E, 24°43’ N
Village	:	Tana (Akola)
Land form	:	Gently slopping plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Pasture/barren

Depth (cm)	**Morphological features**
0-15	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; slight effervescence.
15-30	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and non-plastic; slight effervescence.
30-45	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and non-plastic; slight effervescence.
45-60	Dark brown (10 YR 3/3 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; slight effervescence.
60-75	Dark brown (10 YR 3/3 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; fine irregular calcareous nodules; strong effervescence.
75-90	Dark yellowish brown (10 YR 4/4 M); clay; massive; firm, sticky and plastic; fine lime nodules; violent effervescence.

Table 4.1.11 Morphological description of pedon P_5

Location	:	74°19’ E, 24°57’ N
Village	:	Doveni
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to single crop of mustard

Depth (cm)	Morphological features
0-15	Dark brown (10 YR 3/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; many, very fine roots; slight effervescence.
15-30	Dark brown (10 YR 3/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; firm, slightly sticky and slightly plastic; few, fine roots; slight effervescence.
30-45	Brown (10 YR 4/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; strong effervescence.
45-60	Yellowish brown (10 YR 5/4 M); clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; violent effervescence.
60-75	Yellowish brown (10 YR 5/6 M); clay loam; massive; firm, sticky and plastic; white powdery lime; violent effervescence.
75-90	Yellowish brown (10 YR 5/6 M); clay loam; massive; firm, sticky and plastic; white powdery lime; violent effervescence.

Table 4.1.7 Morphological description of pedon P_6

Location	:	74°16’ E, 24°49’ N
Village	:	Mazola (Babrana)
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to single crop of maize

Depth (cm)	Morphological features
0-15	Dark yellowish brown (10 YR 4/4 M); loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; many, fine roots; slight effervescence.
15-30	Dark yellowish brown (10 YR 4/4 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
30-45	Dark yellowish brown (10 YR 4/5 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
45-60	Brown (10 YR 5/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
60-75	Brown (10 YR 5/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; fine irregular lime nodules; violent effervescence.
75-90	Brown (10 YR 5/3 M); sandy clay loam; massive; friable, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.

Table 4.1.12 Morphological description of pedon P_7

Location	:	74°21' E, 24°53' N
Village	:	Indira Nagar (Mungana)
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated to single crop of wheat

Depth (cm)	**Morphological features**
0-15	Dark grayish brown (10 YR 4/2 M); sandy clay loam; fine, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and non-plastic; strong effervescence.
30-45	Grayish brown (10 YR 5/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
45-60	Brown (10 YR 5/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
60-75	Brown (10 YR 5/3 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
75-90	Light brownish gray (10 YR 6/2 M); clay loam; massive; friable, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.

Table 4.1.13 Morphological description of pedon P_8

Location	:	74°21' E, 24°59' N
Village	:	Dindoli
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to double crop of maize and wheat

Depth (cm)	**Morphological features**
0-15	Brown (10 YR 4/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and non-plastic; many, fine roots; strong effervescence.
15-30	Brown (10 YR 4/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
30-45	Brown (10 YR 4/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
45-60	Dark yellowish brown (10 YR 4/4 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
60-75	Grayish brown (10 YR 5/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
75-90	Grayish brown (10 YR 5/2 M); clay loam; massive; friable, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.

Table 4.1.8 Morphological description of pedon P_9

Location	:	74°20’ E, 24°58’ N
Village	:	Somar Walon Ka Khera (Kundliya)
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to single crop of wheat

Depth (cm)	Morphological features
0-15	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; slight effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
30-45	Brown (10 YR 4/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
45-60	Brown (10 YR 5/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
60-75	Light brownish gray (10 YR 6/2M); clay loam; massive; friable, slightly sticky and slightly plastic; white powdery lime; violent effervescence.
75-90	Light brownish gray (10 YR 6/2 M); clay loam; massive; friable, slightly sticky and slightly plastic; white powdery lime; violent effervescence.

Table 4.1.14 Morphological description of pedon P_{10}

Location	:	74°18' E, 25°03' N
Village	:	Puthwadia
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated to single crop of wheat

Depth (cm)	Morphological features
0-15	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; many, fine roots; slight effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; few, fine roots; slight effervescence.
30-45	Dark grayish brown (10 YR 4/2 M); clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; violent effervescence.
45+	Dark yellowish brown (10 YR 4/4 M); clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; violent effervescence.

Table 4.1.15 Morphological description of pedon P_{11}

Location	:	74°18’ E, 24°31’ N
Village	:	Bhanakheri
Land form	:	Gently slopping land
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to single crop of wheat

Depth (cm)	**Morphological features**
0-15	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
15-30	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
30-45	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
45-60	Dark grayish brown (10 YR 4/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and plastic; fine lime nodules; violent effervescence.
60-75	Brown (10 YR 4/3 M); clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; fine lime nodules; violent effervescence.
75-90	Brown (10 YR 4/3 M); clay loam; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; fine lime nodules; violent effervescence.

Table 4.1.16 Morphological description of pedon P_{12}

Location	:	74°22' E, 24°29' N
Village	:	Samlia
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated to single crop of wheat

Depth (cm)	Morphological features
0-15	Dark grayish brown (10 YR 4/2 M); sandy clay loam; fine, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); sandy clay loam; fine, weak, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
30-45	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
45-60	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
60-75	Dark grayish brown (10 YR 4/4 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
75-90	Dark grayish brown (10 YR 4/4 M); sandy clay loam; massive; friable, slightly sticky and slightly plastic; strong effervescence.

Table 4.1.17 Morphological description of pedon P_{13}

Location	:	74°20’ E, 24°30’ N
Village	:	Dungla
Land form	:	Gently slopping land
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Cultivated to single crop of wheat

Depth (cm)	Morphological features
0-15	Very dark grayish brown (10 YR 3/2 M); loam; fine, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Very dark grayish brown (10 YR 3/2 M); loam; medium, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
30-45	Brown (10 YR 4/3 M); sandy clay loam; medium, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; common, fine roots; violent effervescence.
45-60	Grayish brown (10 YR 5/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; common, fine roots; fine lime nodules; violent effervescence.
60-75	Light brownish gray (10 YR 6/2 M); clay loam; massive; friable, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.
75-90	Light brownish gray (10 YR 6/2 M); clay loam; massive; friable, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.

Table 4.1.18 Morphological description of pedon P_{14}

Location	:	74°16' E, 24°42' N
Village	:	Kumarkhera
Land form	:	Gently slopping land
Parent material	:	Alluvium
Drainage	:	Well drained
Present land use	:	Pasture/barren

Depth (cm)	Morphological features
0-15	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
30-45	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; slight effervescence.
45-60	Brown (10 YR 4/3 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; slight effervescence.
60-75	Grayish brown (10 YR 5/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; slight effervescence.
75-90	Grayish brown (10 YR 5/2 M); clay; medium, moderate, sub-angular blocky structure; firm, sticky and plastic; strong effervescence.

Table 4.1.19 Morphological description of pedon P_{15}

Location	:	74°21’ E, 24°26’ N
Village	:	Delwas (Karsana)
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated to single crop of wheat

Depth (cm)	**Morphological features**
0-15	Very dark grayish brown (10 YR 3/2 M); sandy loam; fine, weak, sub-angular blocky structure; friable, non-sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Very dark grayish brown (10 YR 3/2 M); sandy loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
30-45	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; fine lime nodules; violent effervescence.
45-60	Dark brown (10 YR 3/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.
60-75	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; firm, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.
75-90	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; firm, slightly sticky and slightly plastic; fine lime nodules; violent effervescence.

Table 4.1.20 Morphological description of pedon P_{16}

Location	:	74°18' E, 24°35' N
Village	:	Mangalwar
Land form	:	Plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated to double crop of maize and wheat

Depth (cm)	**Morphological features**
0-15	Dark grayish brown (10 YR 4/4 M); sandy clay loam; fine, weak, sub-angular blocky structure; friable, non-sticky and non-plastic; few, fine roots; slight effervescence.
15-30	Grayish brown (10 YR 5/2 M); sandy clay loam; fine, weak, sub-angular blocky structure; friable, non-sticky and non-plastic; few, fine roots; slight effervescence.
30-45	Brown (10 YR 5/3 M); sandy clay loam; medium, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; slight effervescence.
45-60	Brown (10 YR 5/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; slight effervescence.
60-75	Grayish brown (10 YR 5/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; strong effervescence.
75-90	Light yellowish brown (10 YR 6/4 M); clay loam; massive; firm, sticky and slightly plastic; fine lime nodules; violent effervescence.

Table 4.1.21 Morphological description of pedon P_{17}

Location	:	74°16’ E, 24°36’ N
Village	:	Idra
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated to single crop of sorghum (fodder)

Depth (cm)	**Morphological features**
0-15	Dark grayish brown (10 YR 4/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; strong effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; violent effervescence.
30-45	Grayish brown (10 YR 5/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; violent effervescence.
45-60	Brown (10 YR 5/3 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
60-75	Light brownish gray (10 YR 6/2 M); clay loam; massive; friable, sticky and plastic; fine irregular calcareous nodules violent effervescence.
75-90	Light brownish gray (10 YR 6/2 M); clay loam; massive; friable, sticky and plastic; fine lime nodules; violent effervescence.

Table 4.1.22 Morphological description of pedon P_{18}

Location	:	74°53' E, 24°04' N
Village	:	Dabda
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated to double crop of maize and wheat

Depth (cm)	**Morphological features**
0-15	Very dark grayish brown (10 YR 3/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; violent effervescence.
15-30	Very dark grayish brown (10 YR 3/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
30-45	Dark grayish brown (10 YR 4/2 M); clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
45-60	Dark yellowish brown (10 YR 4/4 M); clay loam; massive; firm, sticky and plastic; violent effervescence.
60-75	Dark grayish brown (10 YR 5/2 M); clay; massive; firm, sticky and plastic; white powdery lime; violent effervescence.
75-90	Dark grayish brown (10 YR 5/2 M); clay; massive; firm, sticky and plastic; white powdery lime; violent effervescence.

Table 4.1.9 Morphological description of pedon P_{19}

Location	:	74°59’ E, 25°01’ N
Village	:	Jai Nagar
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Cultivated occasionally/pasture

Depth (cm)	**Morphological features**
0-15	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Very dark grayish brown (10 YR 3/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; few, fine roots; violent effervescence.
30-45	Dark brown (10 YR 3/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
45-60	Dark brown (10 YR 3/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; firm, slightly sticky and plastic; violent effervescence.
60-75	Dark grayish brown (10 YR 4/2 M); clay loam; massive; firm, sticky and plastic; fine lime nodules; violent effervescence.
75-90	Dark grayish brown (10 YR 4/2 M); clay loam; massive; firm, sticky and plastic; fine lime nodules; violent effervescence.

Table 4.1.23 Morphological description of pedon P_{20}

Location	:	74°50' E, 25°06' N
Village	:	Rupkhera (Rajgarh)
Land form	:	Nearly levelled plain
Parent material	:	Alluvium
Drainage	:	Moderately well drained
Present land use	:	Barren/pasture

Depth (cm)	**Morphological features**
0-15	Dark brown (10 YR 3/3 M); sandy clay loam; fine, weak, sub-angular blocky structure; friable, slightly sticky and non-plastic; few, fine roots; strong effervescence.
15-30	Dark grayish brown (10 YR 4/2 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; common, fine roots; violent effervescence.
30-45	Dark yellowish brown (10 YR 4/4 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
45-60	Brown (10 YR 5/3 M); sandy clay loam; medium, moderate, sub-angular blocky structure; friable, slightly sticky and slightly plastic; violent effervescence.
60-75	Light brownish gray (10 YR 6/2 M); clay loam; massive; firm, sticky and plastic; fine irregular calcareous nodules; violent effervescence.
75-90	Light brownish gray (10 YR 6/2 M); clay loam; massive; firm, sticky and plastic; fine lime nodules; violent effervescence.

4. EXPERIMENTAL RESULTS

An investigation was carried out to characterize the salt-affected soils and water resources of Sub-humid Southern Plains of Rajasthan (district Chittorgarh). The morphological, physical and chemical properties of the salt-affected soils and quality of irrigation water were studied and the experimental results obtained during the investigation are presented in this chapter under the following heads:

4.1 Characterization of soil

- 4.1.1 Morphological features
- 4.1.2 Physical characteristics
- 4.1.3 Chemical characteristics
- 4.1.4 Nutrient status
- 4.1.5 Nature and extent of salt-affected soils

4.2 Taxonomic classification of soil

4.3 Ground truth

4.4 Chemical composition of well water

4.5 Alternate and sustainable land use planning

4.6 Constraints analysis for sustainable agriculture

4.1 CHARACTERIZATION OF SOIL

Salt-affected soils present diverse problems and differ greatly from normal soils in respect of morphological features, physical properties and chemical characteristics. The concentration and chemistry of the salt solutions can be rather different and consequently a great diversity of salt-affected soils appears. They show wide variations from place to place and have been distinguished into certain categories, the important ones being the saline and sodic soils.

For the ease of comparison of results of the soil samples analyzed from twenty pedons as well as to analyze constraints for sustainable management, weighted mean of ECe and ESP of each pedon was computed (Table 4.1.1) from the detailed data presented in table 4.1.27 and 4.1.31. The pedons were grouped according to salinity and sodicity appraisal (Table 4.1.2 and 4.1.3) as suggested by Soil Survey Division Staff (1995). Categorization of pedons based on salinity appraisal (Table 4.1.2) clearly indicated that thirteen (65 %) pedons comes under non-saline, while, seven (35 %) pedons comes under very slightly saline soils. However, when we categorize the pedons under study based on sodicity appraisal (Table 4.1.3) indicated that 30 per cent (six pedons) comes under slight to moderate sodic soil and 70 per cent (fourteen pedons) comes under moderate to highly sodic soils. Therefore, it seems to be more appropriate to categorize the salt-affected soils of Chittorgarh district based on sodicity appraisal.

Table 4.1.1 Weighted mean of ECe and ESP for pedons

Pedons	ECe (dS m^{-1})	ESP	Pedons	ECe (dS m^{-1})	ESP
P_1	1.86	25.41	P_{11}	1.55	31.11
P_2	1.60	16.60	P_{12}	1.38	33.30
P_3	2.89	32.89	P_{13}	1.49	35.39
P_4	2.17	23.25	P_{14}	2.38	34.17
P_5	1.59	32.01	P_{15}	2.16	40.00
P_6	1.72	25.12	P_{16}	1.50	35.98
P_7	1.57	42.21	P_{17}	1.76	37.67
P_8	1.34	32.13	P_{18}	2.19	34.81
P_9	3.85	22.73	P_{19}	0.71	20.09
P_{10}	1.64	32.68	P_{20}	3.63	35.93

Table 4.1.2 Categorization of pedons based on salinity appraisal

Class	ECe (dS m^{-1})	Pedons
S_1 Non saline	< 2.0	P_1, P_2, P_5, P_6, P_7, P_8, P_{10}, P_{11}, P_{12}, P_{13}, P_{16}, P_{17}, P_{19}
S_2 Very slightly saline	2.0-4.0	P_3, P_4, P_9, P_{14}, P_{15}, P_{18}, P_{20},
S_3 Slightly saline	4.0-8.0	None
S_4 Moderately saline	8.0-16.0	None
S_5 Strongly saline	> 16.0	None

Table 4.1.3 Categorization of pedons based on sodicity appraisal

Class	ESP	Pedons
S_1 None to slight	< 15	None
S_2 Slightly to moderate	15-30	P_1, P_2, P_4, P_6, P_9, P_{19}
S_3 Moderate to high	30-50	P_3, P_5, P_6, P_7, P_8, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}, P_{15}, P_{16}, P_{17}, P_{18}, P_{20}
S_4 High to very high	> 50	None

4.1.1 Morphological Features:

Soil morphology has been studied largely under field conditions. The morphology of a soil is best evaluated from the *in situ* examination of the soil profile. The study includes examination of soil colour, texture, structure, consistency, calcareousness, roots, nodules, concretions and some other special features, if any.

The importance of morphology in soil genesis studies can be realized from the statement of Joffe (1949), "soil morphology uncovers to the pedologists a number of facts which help to unravel many complicated problems of soil genesis. The morphological features of the soil profile are the mirror image of the processes responsible for the formation of this or that type of soil. Soil morphology is the stepping stone to the anatomical features (morphological characteristics) of the soil profile supplemented by physiological and histological (physical, chemical and biological characteristics) analysis which brings out the uniqueness of the soil body."

The morphological features observed in the field about the pedons under study are presented in table 4.1.4 to 4.1.23.

(a) Slight to moderate sodic soils (ESP 15-30) :

Slight to moderate sodic soils of Chittorgarh district covers the pedons P_1, P_2, P_4, P_6, P_9 and P_{19} located in panchayat samiti Bhopalsagar (P_1, P_2, P_4), Kapasin (P_6), Rashmi (P_9) and Begun (P_{19}).

A perusal of description of the morphological features of the slight to moderate sodic soils presented in table 4.1.4 to 4.1.9 indicated that soils are slightly deep to moderately deep and well drained. The soil exhibited very dark grayish brown (10 YR 3/2 M) to light brownish gray (10 YR 6/2 M) colour, with sandy clay loam to clay loam texture, massive to sub-angular blocky structure and strong to violent reaction with dilute HCl. The soils of above category were mostly used for raising a single crop in the want of irrigation facilities, however, the area represented by pedon P_4 was a Government land reserved for pasture. The results of morphological features presented in table 4.1.4 to 4.1.9 also indicated that the effervescence becomes violent at or after 30 cm depth in most of the pedons indicating enrichment of horizon with calcium carbonate.

(b) Moderate to highly sodic soils (ESP 30-50):

Moderate to highly sodic soils of Chittorgarh district covers the pedons P_3, P_5, P_7, P_8, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}, P_{15}, P_{16}, P_{17}, P_{18} and P_{20} located in panchayat samiti Bhopalsagar (P_3), Kapasin (P_5, P_7), Rashmi (P_8, P_{10}), Dungla (P_{11}, P_{12}, P_{13}, P_{14}, P_{15}, P_{16}, P_{17}), Pratapgarh (P_{18}) and Begun (P_{20}).

The morphological characters of moderate to highly sodic soils presented in table 4.1.10 to 4.1.23 showed that soils of this category were shallow to moderately deep, developed on an alluvial material. These soils are characterized by very dark grayish brown (10 YR 3/2 M) to light brownish gray (10 YR 6/2 M) colour, dominated with sandy clay loam to clay loam texture. The soils of this category have a massive to sub-angular blocky structure. Owing to high ESP and poor physical conditions their productivity, in general, for *rabi* (wheat) crops is very low or otherwise lying barren. Wherever, opportunities are available they are being cultivated after addition of tank bed soil on the surface transported from nearby tank. The practice of addition of tank bed soil is repeated after three to four years depending upon the availability.

4.1.2 Physical Characteristics:

Soil physical characteristics profoundly influence how soils function in an ecosystem and how they can best be managed. The occurrence and growth of many plant species are closely related to soil physical properties, which are governed by the movement of water over and through the soil carrying dissolved nutrients and chemical pollutants. Maintenance of favourable physical conditions in soil is a prerequisite in soil management for the better plant growth in sustainable agriculture. Several parameters like bulk density, particle density, porosity, mechanical separates and water retention characteristics have been analyzed and used to describe physical condition of the soils under study. The data on physical characteristics of the soils are presented in table 4.1.24 to 4.1.26.

(a) Bulk density:

Bulk density is an important mass measurement of soil, which is defined as the mass of a unit volume of dry soil. This volume includes both solids and pores.

Slight to moderate sodic soils (ESP 15-30):

An examination of data presented in table 4.1.24 indicated that the bulk density in different pedons of slight to moderate sodic soils ranged between 1.42 to 1.62 Mg m^{-3}. It is also apparent from the data that the value of bulk density increases as one proceeds down the pedons. In general, a lower value of bulk density was observed in surface layer (0-15 cm) and the highest value in the bottom layer of the pedon.

Moderate to highly sodic soils (ESP 30-50):

A perusal of data on bulk density (Table 4.1.24) of moderate to highly sodic soils indicated that the values of this parameter ranged between 1.41 to 1.62 Mg m^{-3}. In general, surface horizons recorded the lower value of bulk density and the values recorded an increase alongwith depth of the pedons examined.

(b) Particle density:

Particle density is often considered as an index of soil mineralogy. Soil profiles showing high values indicating concentration of heavy minerals whereas, lower values depict preponderance of light minerals. Particle density is not affected by pore space and therefore, is not related to particle size or to the arrangement of particles (soil structure).

Slight to moderate sodic soils (ESP 15-30):

It is evident from the examination of data presented in table 4.1.24 that the particle density values of all the soils under study pertaining to slight to moderate sodic soils varied from 2.46 to 2.69 Mg m^{-3}. It is further apparent from the perusal of data that the values of particle density increases alongwith depth of profile, except the pedon P_1, where a little decrease was observed in bottom most horizon as compared to surface horizon.

Moderate to highly sodic soils (ESP 30-50):

A perusal of data presented in table 4.1.24 the particle density of moderate to highly sodic soils indicated that the values observed for all the soils under study ranged between 2.46 to 2.73 Mg m^{-3}. The highest value of this parameter was recorded in the bottom most horizon of pedon P_{16} (2.73 Mg m^{-3}) and lowest value was recorded in the subsurface horizon (15-30 cm) of pedon P_8 (2.46 Mg m^{-3}). Like that of bulk density, the particle density of soils also increases with an increase in the depth of the pedon, except in pedon P_8 and P_{15}, where a little lower value of particle density was observed for the subsurface horizons as compared to surface horizon.

(c) Porosity:

Porosity is one of the main parameter indicating the movement of water and/or air in the pedon. It mainly varies with the variation in bulk density of the soil. For soils with the same particle density, the lower the bulk density, the higher the per cent pore space (total porosity).

Slight to moderate sodic soils (ESP 15-30):

An examination of data on porosity (Table 4.1.24) revealed that the overall range varied between 37.69 to 44.96 per cent. In general, relatively higher values have been observed in surface horizon as compared to bottom most horizons. However, total porosity values for the remaining lower subsurface horizons of the pedons under investigation did not exhibit any specific trend. The highest value of porosity was recorded in surface horizon of the pedon P_9 while the least value was recorded in the bottom most horizon (75-90 cm) of pedon P_2.

Moderate to highly sodic soils (ESP 30-50):

It is apparent from the perusal of data on total porosity (Table 4.1.24) that the values ranged between 38.95 to 45.17 per cent in different layers of various pedons of moderate to highly sodic soils examined. A relatively higher value of porosity has been observed in surface horizon as compared to subsurface horizon. Further, total porosity values for the remaining lower subsurface horizon of the pedons under investigation did not exhibit any specific trend.

(d) Particle size distribution:

The size of mineral particles in soil may seem too mundane a subject to warrant much attention, yet knowledge of the proportions of different sized particles in a soil is critical for understanding soil behaviour and management. For investigating soils on a site, the particle size distribution of various soil depth is often the first and most important property to determine. Furthermore, texture (particle size distribution) of a soil in the field is not readily subjected to change, so it is considered a basic property of a soil.

Slight to moderate sodic soils (ESP 15-30):

A critical examination of data on mechanical separates of slight to moderate sodic soils (Table 4.1.25) revealed that a wide variation in the content of sand fraction was recorded ranging from 38.3 to 62.9 per cent. Based on weighted mean value computed it was maximum in the pedon P_2 (51.0 %) and minimum in pedon P_9 (46.8 %). Further, the sand content under study did not exhibit any specific trend along the depth of the pedon although a lower value of sand content was observed in bottom most depth of the pedons examined.

Perusal of the data on silt content of the slight to moderate sodic soils indicated that like sand, silt fraction also showed a wide variation in its content ranging between 6.6 to 30.5 per cent. Based on weighted mean the highest value of the silt fraction was observed in pedon P_{19} (27.3 %), while, the least value was recorded in pedon P_4 (14.8

%). It is further evident from the examination of data that the silt fraction in various soil layers of the pedons pertaining to slight to moderate sodic soils did not exhibit any relationship with depth of the pedons. However, the silt content in pedon P_6 when compared with its content in the other layers an abrupt decrease was observed at a depth of 60-75 cm. The distribution of clay fraction presented in table 4.1.25 when examined indicated that its content varied from 19.9 to 41.9 per cent in various pedons of this group. In general, clay content increases with depth of the profile except pedon P_6 where maximum clay content was observed in 60-75 cm depth.

Moderate to highly sodic soils (ESP 30-50):

The data on the distribution of sand fraction in moderate to highly sodic soils of district Chittorgarh (Table 4.1.25) indicated a wide variation ranging from 28.9 to 67.3 per cent. Pedon P_8, P_{12}, P_{15} and P_{16} have relatively higher proportion of sand fraction [> 50 per cent (50.3 to 54.7%) as a weighted mean] as compared to the other pedons classified under this group [< 50 per cent (33.9 to 48.56%) as a weighted mean]. When compared with the value observed in the surface horizon, in general, there is a decrease in sand content in the subsurface horizons but the sand content of the pedons under study did not exhibit any specific trend in the subsequent depth of the pedons except in pedon P_5 and P_{11} where a regular decrease alongwith the depth of the profile have been recorded.

Silt fraction of the moderate to highly sodic soils constitutes 9.0 to 41.6 per cent in the particle size distribution (Table 4.1.25) of the soil pedons under study. It can be inferred from the data that the highest value of silt (35.8 per cent as a weighted mean) was observed in pedon P_{17} and the least value (12.9 per cent as a weighted mean) was observed in pedon P_{11}. A critical examination of data further revealed that the silt fraction showed a decrease alongwith the depth of pedons in P_3 and P_{18} while a definite enrichment of the bottom most horizon was observed in pedons P_7, P_8, P_{15}, P_{16} and P_{20}. However, in rest of the pedons examined in this group, in general, did not indicate any specific trend alongwith the depth of the pedons examined.

Perusal of data on the distribution of clay fraction presented in table 4.1.25 indicated that its content varied from 17.6 to 60.8 per cent. In general, the surface horizon show relatively lower content of clay fraction as compared to subsurface horizons examined. It is further evident from the data that the clay content in various layer of the pedons exhibited an increasing trend alongwith depth of the pedon except in pedon P_8 where irregularity in clay content was observed throughout the depth of the pedon examined.

(e) Water retention characteristics :

The availability of water to plants depends mainly on total water content of the soil and the soil properties influencing its retention and release. The crop productivity on a soil depends on the water storage capacity of soil and its availability. A sound knowledge about water retention characteristics is an important parameter in crop management.

The portion of capillary water lying between field capacity (0.033 MPa) and wilting coefficient (1.5 MPa) is categorized to be available water for plants. It functions as the soil solution and is influenced by the organic matter content and texture of the soil. The results on soil moisture characteristics at -0.033 MPa and -1.5 MPa are described in the light of the data presented in table 4.1.26.

Slight to moderate sodic soils (ESP 15-30):

The data pertaining to soil moisture retention characteristics are presented in table 4.1.26 of the slight to moderate sodic soils. From the perusal of data it can be inferred that an overall range of moisture retention at -0.033 and -1.5 MPa varied between 0.17 to 0.41 and 0.09 to 0.24 m^3 m^{-3}, respectively. However, an exceptionally low value (0.04 m^3 m^{-3}) was observed for pedon P_{19} in lower horizon (60-75 cm) at -1.5 MPa. A further examination of data revealed that retention of water was higher in the surface soil layer (0-15 cm) as compared to subsurface horizon (15-30 cm) at both the tension (0.033 and 1.5 MPa) under investigation except for pedon P_4 at -0.033 MPa.

Moderate to highly sodic soils (ESP 30-50):

Perusal of data on water retention at 0.033 MPa (Table 4.1.26) revealed that the values ranged between 0.20 to 0.39 m^3 m^{-3} in moderate to highly sodic soils under investigation. Further, it is also evident from the data that a low amount of water was retained at surface layer (0-15 cm) of pedon P_7, P_{12}, P_{14}, P_{15}, P_{16} and P_{20} as compared to subsurface layer (15-30 cm), while in rest of the pedons a reverse trend was observed. An examination of data on the amount of water retained at 1.5 MPa tension indicated an overall range of 0.08 to 0.21 m^3 m^{-3}. It can also be inferred from the data that subsurface horizon (15-30 cm) showed higher water retention at 1.5 MPa tension in pedon P_8, P_{12}, P_{14}, P_{15}, P_{16} and P_{20}, while in rest of the pedons a reverse trend was observed.

(f) Available water capacity (AWC):

The moisture held between the field capacity (0.033 MPa) and PWP (1.5 MPa) may not be actually available to crops though it is considered as available. Hence, plant available water capacity (PAWC) was calculated for the control section following the formula proposed by Gardner *et al.* (1984) to draw an inference for water retention behavior of the soils under study.

Slight to moderate sodic soils (ESP 15-30):

The available water capacity of slight to moderate sodic soils ranged between 0.11 to 0.20 $m^3 m^{-3}$ (Table 4.1.26). Further, the PAWC values of different pedons ranged between 93.0 to 138.0 mm, with the lowest value in pedon P_{19} (93.0 mm) and highest value in pedon P_2 (138.0 mm).

Moderate to highly sodic soils (ESP 30-50):

A critical examination of data presented in table 4.1.26 revealed that the available water capacity values varied between 0.11 to 0.22 $m^3 m^{-3}$. A thorough examination of data in various pedons indicated that available water distributed unevenly as one proceeds down the depth and no specific trend could be established. Further, the plant available water capacity (PAWC) values ranged between 85.0 to 136.5 mm in various pedons under investigation with a distinctly lowest value in pedon P_{10} having the minimum depth of the pedon (+45 cm).

4.1.3 Chemical characteristics:

Electrical conductivity and pH of the soil saturation extract and exchangeable sodium percentage are the most commonly used parameters for the appraisal of salinity and sodicity hazards in soil. Apart from these parameters organic carbon, calcium carbonate, water soluble ions and exchange phenomenon of the soil were also determined and described in this section under the suitable heads (Table 4.1.27 to 4.1.31).

(a) Soil reaction and electrical conductivity:

pH is one of the most important chemical parameter controlling availability of plant nutrients in the soil and has been widely recognized as an index, distinguishing alkali soils from the normal or saline soils, while, ECe of the soil influences plant growth indirectly through influencing the soil water potential. ECe is used as a parameter for salinity appraisal.

Slight to moderate sodic soils (ESP 15-30):

A perusal of data presented in table 4.1.27 revealed that the pH of this group ranged between 7.94 to 9.57. Further, the pH values followed an increasing trend alongwith depth of pedon except in pedon P_2 where a higher pH value was observed in surface layer (0-15 cm) as compared to subsurface horizon (15-30 cm). It can also be inferred from the examination of data that the soils of this group are sodic in nature since the pH value exceeded 8.2 (as a weighted mean).

A critical examination of data on ECe presented in table 4.1.27 revealed a wide variation in ECe ranging between 0.59 to 4.32 dS m^{-1} in this group of soils, however based on weighted mean the ECe value did not exceeded 2 dS m^{-1} except in pedon P_4 (2.17 dS m^{-1}) and P_9 (3.85 dS m^{-1}). Thus, the soils of pedons P_1, P_2, P_6 and P_{19} could be designated as non-saline, while, that of pedon P_4 and P_9 as very slightly saline soils. ECe values when examined down the depth of pedon, in general, registered an increasing pattern in pedon P_1, while, other pedons did not exhibit any specific trend.

Moderate to highly sodic soils (ESP 30-50):

The data on pH related to moderate to highly sodic soils are presented in table 4.1.27 which, when examined showed a wide variation, ranging between 8.06 to 10.05. In general, pH values increases as one proceeds from surface to sub-soil horizons of the pedons under investigation. A distinctly higher value of pH was recorded in the lower most horizon of the pedons except in the pedons P_{12} and P_{16}. It can also be inferred from the examination of data that the soils of this group are sodic in nature since the pH value varied between 8.8 to 9.8 (as a weighted mean).

An examination of data on electrical conductivity (ECe) revealed that the value observed ranged between 0.91 to 5.46 dS m^{-1}. The soils of pedon P_{20} exhibited a higher range of salinity (2.33 to 5.46 dS m^{-1}) with a weighted mean of 3.63 dS m^{-1} followed by pedon P_3 (2.68 to 3.14 dS m^{-1}) with a weighted mean of 2.89 dS m^{-1}. Rest of the pedons were found to have a lower range of ECe ranging from 0.91 to 3.14 dS m^{-1} with a weighted mean ranging between 1.34 to 2.38 dS m^{-1}. Further examination of data revealed that, in general, a higher value of ECe was observed in bottom most horizon except in pedons P_{17} and P_{20} where in the higher value was observed in surface soil horizon (0-15 cm), while, in pedon P_{18} a higher ECe value were observed in subsurface horizon (15-30 cm). Soils of pedon when examined down the depth, in general, ECe value did not exhibit any specific trend except in pedon P_8 which has showed an increasing trend alongwith depth of pedon examined.

(b) Organic carbon:

The presence of organic matter in soil gives a symbol of life in soil. It contains, retains and supplies all essential nutrients, although in low and variable amounts. It thus asserts an abiding influence on sustenance of soil fertility (including erodibility and compactibility). The organic carbon has greater positive influence on the soil quality. In general, the content of organic carbon decreases with soil depth.

Slight to moderate sodic soils (ESP 15-30):

Perusal of data pertaining to organic carbon content of the soils under investigation (Table 4.1.27) indicated a range between 0.42 to 7.60 g kg^{-1}. It is further evident that the higher value of organic carbon was noticed at the surface layer, which progressively decreased as one proceeds down the pedon in almost all the pedons examined. From the data it can be observed that a relatively higher value of organic carbon was recorded in pedon P_4 with a weighted mean of 5.17 g kg^{-1} and lower value was observed in pedon P_{19} with a weighted mean of 2.85 g kg^{-1}.

Moderate to highly sodic soils (ESP 30-50):

An examination of data on organic carbon content of the soil, presented in table 4.1.27 revealed that organic carbon content ranged between 0.42 to 7.89 g kg^{-1}. The distribution of organic carbon invariably showed a decreasing trend with an increase in the depth of various pedons examined. The variation observed for this parameter was not much profound from one pedon to another, although some of the horizons (surface) have shown unusual higher values of organic carbon. Further, it was also evident that a maximum organic carbon content (4.84 g kg^{-1} as a weighted mean) was recorded in pedon P_{10}, while, the lowest amount (1.92 g kg^{-1} as a weighted mean) was recorded for pedon P_{17} in moderate to highly sodic soils of Chittorgarh district.

(c) Calcium carbonate:

Calcium carbonate commonly accumulates in saline or alkali soils developed under arid and semi-arid climates. The accumulation may be diffused throughout the soil profile, or may take the form of soft concretions or nodules or powdered form or may be concentrated in a continuous horizon of different hardness and at different depths below the surface. The presence of $CaCO_3$ affects both the physical and chemical properties of a soil. The water movement is restricted and root penetration and proliferation are also prevented. Highly calcareous soils ($CaCO_3$ > 2%) suffer seriously with macro and micronutrients deficiencies and/or nutrient imbalances.

Slight to moderate sodic soils (ESP 15-30):

It is apparent from the examination of data elucidated in table 4.1.27 that calcium carbonate constituted a significant part of the soils under study. It ranged between 26.2 to 530.0 g kg^{-1} indicating the calcareous nature of the soils under study.

The distribution of calcium carbonate invariably showed an increasing pattern with an increase in the depth of various pedons examined indicating the process of leaching down of calcium and subsequent precipitation at some lower depths.

Moderate to highly sodic soils (ESP 30-50):

A critical examination of data presented in table 4.1.27 on calcium carbonate content indicated that the $CaCO_3$ value ranged between 15.0 to 664.0 g kg^{-1} in moderate to highly sodic soils. The amount of calcium carbonate recorded was least in surface horizon (0-15 cm) and highest in the lower most horizon (75-90 cm) with an exception in pedon P_8 and P_{12} where surface horizon (0-15 cm) exhibited a higher value of $CaCO_3$ than the subsurface horizons (15-30 cm). In general, the magnitude of build up of $CaCO_3$ was much more in horizons located beyond 45 cm depth in almost all the pedons examined under moderate to highly sodic soils.

(d) Water soluble cations:

Water soluble sodium, potassium, calcium and magnesium are of interest from the view point of soil salinity considerations. These cations are used to calculate sodium adsorption ratio, which is an important indicator of sodicity.

Slight to moderate sodic soils (ESP 15-30):

The data on water soluble cations are presented in table 4.1.28. A perusal of water soluble cationic composition of these soils revealed that sodium is the dominant cation and its concentration ranged between 3.3 to 27.5 me l^{-1}, while that of calcium and magnesium varied between 1.2 to 10.8 and 1.0 to 6.8 me l^{-1}, respectively. Further, the soluble potassium constitutes a small quantity and ranged between 0.2 to 1.8 me l^{-1}. Thus their relative presence can be stated as Na > Ca > Mg > K. A critical examination of data further revealed that, in general, the sodium fraction was found comparatively lower in surface and higher at the bottom most layers. Further, the sodium content, in general, increases downward with depth except in pedon P_2 and P_6. However, calcium and magnesium did not show any trend with depth of the pedons examined. The water soluble potassium also did not show any trend along the depth of the pedons under study.

Moderate to highly sodic soils (ESP 30-50):

A perusal of data on soluble cations presented in table 4.1.28 indicated the preponderance of sodium among cations. The concentration varied between 5.2 to 29.4, 1.5 to 14.1, 1.0 to 8.2 and 0.2 to 2.9 me l^{-1} for sodium, calcium, magnesium and potassium, respectively, and thus their relative presence can be stated as Na > Ca > Mg >

K. Further, it was also noticed that calcium and magnesium content was higher in surface horizon and lower in bottom most horizon except in pedon P_8, P_{10} and P_{11} where no definite trend in their content was observed. In general, the water soluble sodium content increased with an increase in the depth of the pedon except in pedons P_3, P_{12}, P_{13}, P_{14}, P_{16}, P_{18} and P_{20}. A bimodal pattern (first decreasing then after some depth increasing pattern) about the water soluble sodium was observed in pedon P_3, P_{13}, P_{14}, P_{16} and P_{20}, while, pedon P_{12} and P_{18} does not showed any specific trend. As regard water soluble K content, a very narrow range was observed. In general, the potassium content decreased with an increase in the depth of pedon leaving aside few exceptions.

(e) Water soluble anions:

The content and distribution of carbonates, bicarbonates, sulphates and chlorides of alkali and alkaline earth metals in the pedon are of particular interest for consideration while describing the chemical properties of salt-affected soils.

Slight to moderate sodic soils (ESP 15-30):

The distribution of water soluble anions presented in table 4.1.29 for slight to moderate sodic soils of Chittorgarh district when examined clearly indicated that chloride fraction dominated among the anions measured. The chloride, sulphates and bicarbonate content varied between 3.0 to 32.0, traces to 13.5 and 2.0 to 7.2 me l^{-1}, respectively, in various pedons under study. A small amount of carbonate was also observed only in few horizons of the pedons examined ranging between 1.6 to 2.8 me l^{-1}. Further, bicarbonate ion distribution registered an increasing trend as one proceeds down the depth of the pedons in pedon P_4, P_6 and P_9, while in pedon P_{19} no specific pattern was registered and in pedons P_1 and P_2 a decreasing trend was observed. Thus it can be narrated that, in general, this group of pedons did not showed any specific trend alongwith depth of the pedon for the content of water soluble bicarbonate under study. The chloride content of the soils under investigation also registered an increasing trend down the depth of the pedons examined except in pedon P_1 and P_{19} where an irregular distribution was recorded. In general, the SO_4^{-2} content decreased alongwith depth of pedon leaving aside few exceptions.

Moderate to highly sodic soils (ESP 30-50):

A perusal of anionic composition of moderate to highly sodic soils of Chittorgarh district presented in table 4.1.29 indicated that among the anions the chloride ions dominated followed by bicarbonate and sulphate, while, the carbonate ions were almost absent. The overall distribution of chloride, bicarbonate and sulphate ions recorded ranged between 5.0 to 33.0, 2.4 to 8.2 and traces to 13.6 me l^{-1}, respectively in various pedons under study. Further, it was also noticed that the bicarbonate content of subsurface horizons when compared with its content in surface horizons a definite build up have been registered in almost all the pedons except surface horizon of pedon P_{10} and P_{12} where the values were almost equal to bottom most horizon. The data further indicated that the chloride content increased with depth of pedons examined in pedon P_8, P_9, P_{10}, P_{11}, P_{13} and P_{15}. A bimodal pattern (first decrease than increase) about the chloride content was observed in P_7, P_{12}, P_{14}, P_{16}, P_{18} and P_{20}, while, pedon P_3 and P_5 did not showed any trend. It was also evidenced from the data related to water soluble sulphate content which showed, in general, decreasing trend alongwith depth of the pedons under study.

(f) Exchange phenomenon:

The phenomenon of cation exchange is next in importance to photosynthesis in agriculture. It is exhibited by organic and inorganic colloids having negative charges at their surfaces. The isomorphous substitution in the lattice and the broken bonds created by ionization of hydroxyl groups at the edges are responsible for producing negative charges in clays. In the organic colloids negative charges arises from the dissociation of phenolic and carboxyl groups. Calcium, magnesium, sodium and potassium are the common exchangeable cations of soils being alkaline in reaction.

Physical and chemical processes like weathering of minerals, nutrient absorption by plants, swelling and shrinkage of clays and leaching of electrolytes and electrokinetic potential of a soil are governed by the kind of exchangeable cation predominated on the exchange complex. Thus, the exchange phenomenon can be considered to be the most important parameter governing all the processes occurring in the soil. Since exchangeable cations are available to plants, the CEC of a soil determines its nutrient supplying power. The physical properties of soil like aggregation or structural stability are controlled by the cation species held at the surfaces of clays. The soil saturated with calcium and magnesium or potassium provide favourable physical environment for plant growth, however, sodium on the other hand, when predominates among the exchangeable cations disperse the soil aggregate and deteriorates the physical conditions which may even lead to the soil to be devoid of vegetation.

(i) Exchangeable cations:

Slight to moderate sodic soils (ESP 15-30):

The data pertaining to the exchangeable cations are presented in table 4.1.30. Perusal of data revealed that exchangeable calcium was the dominating cation on the exchange complex, followed by magnesium, sodium and potassium in descending order ($Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$). The content of exchangeable calcium ranged between 5.90 to 9.81 cmol (p^{+}) kg^{-1}, whereas, that of exchangeable magnesium, sodium and potassium varied between 3.44 to 7.92, 2.37 to 8.61 and 0.25 to 1.25 cmol (p^{+}) kg^{-1}, respectively. When compared with the values observed in soils for surface to subsurface horizon of various pedons examined, it can be inferred from the data that surface horizon showed a lower values than subsurface horizons for exchangeable calcium, magnesium and sodium except for calcium content in pedon P_1, P_2 and P_9, magnesium content in pedon P_1, P_2, P_9 and P_{19} and sodium content in pedon P_1, P_2 and P_{19} where surface horizon have values more than its subsequent horizon. On the other hand the layers below 30 cm, in general, showed a bimodal pattern for all the exchangeable cations in almost all the pedons with depth of the pedons examined.

Moderate to highly sodic soils (ESP 30-50):

The exchangeable cations of moderate to highly sodic soils in present investigation are presented in table 4.1.30. Perusal of data revealed that the exchangeable calcium, magnesium, sodium and potassium content ranged between 3.82 to 11.78, 1.89 to 9.87, 2.84 to 15.63 and 0.24 to 1.25 cmol (p+) kg^{-1}, respectively. Based on weighted mean, in general, the order of exchangeable cations was $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$ in this group of soils. Among the cations, sodium dominates the exchange complex in almost all the pedons except pedon P_8, P_{10} and P_{11}. A critical look on the data clearly evidenced a relatively higher value of exchangeable calcium, magnesium and sodium in the soils of pedon P_{11} and P_{18} as compared to other pedons as is also evident from the respective weighted mean computed for these cation, 9.57 to 10.54, 8.08 to 8.54 and 9.86 to 11.16 cmol (p+) kg^{-1} as against the range recorded in the rest of pedons 4.35 to 8.20, 2.34 to 6.48 and 6.18 to 8.72 cmol (p+) kg^{-1} for calcium, magnesium and sodium, respectively. It is further apparent from the data that exchangeable sodium values showed an increasing trend alongwith depth of pedon except in pedon P_{12}, which did not exhibit any specific trend along the depth of the pedons. As regard the exchangeable calcium content a lower value was recorded in the surface horizon (0-15 cm) as against the subsurface (15-30 cm) horizon in the soils of pedon P_5, P_8, P_{12}, P_{14} and P_{20} while a reverse trend was observed for the other pedons under investigation.

(ii) Cation exchange capacity (CEC):

Slight to moderate sodic soils (ESP 15-30):

The result of cation exchange capacity are presented in table 4.1.30. A perusal of data revealed that the CEC values varied between 15.89 to 26.92 cmol (p+) kg^{-1} in different pedons examined in the present study, though, the variation of cation exchange capacity within the pedon was narrow. From the data it is further evident that like that of clay content (Table 4.1.25) the CEC of soils showed an increasing trend with an increase in the depth of various pedons examined (except in pedon P_1, P_2 and P_{19}), suggesting that the clay content of the soils has direct bearing on the CEC value of the soils. A bimodal pattern about the CEC was observed in the pedon P_1, P_2 and P_{19}. Further, a relatively higher value was observed in bottom most horizons as compared to surface horizon in almost all the pedons examined.

Moderate to highly sodic soils (ESP 30-50):

A critical examination of data on CEC (Table 4.1.30) in moderate to highly sodic soils of Chittorgarh district showed a wide variation and ranged between 12.49 to 38.97 cmol (p+) kg^{-1} with a maximum value in bottom most horizon of pedon P_{11} and minimum value in surface horizon of pedon P_{20}. When compared with the value obtained for surface horizon, in general, a higher value was registered in subsurface horizon (15-30 cm) in almost all the pedons examined except pedons P_{10}, P_{11}, P_{13} and P_{18} where a lower value was observed as compared to surface horizon. Based on weighted mean, a higher value of CEC was registered for pedon P_{18} and P_{11} with a weighted mean value of 31.35 and 30.98 cmol (p+) kg^{-1}, respectively, as compared to the weighted mean recorded for other pedons under study ranging between 16.87 to 25.06 cmol (p+) kg^{-1}. Further, in all the pedons under study falling in this group a higher value of CEC was recorded in bottom most horizon.

(g) Exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR):

ESP or SAR is usually a good indicator of the structural stability of a soil and of the physical response that may be anticipated when water is applied.

The exchangeable sodium percentage (ESP) identifies the degree to which the exchange complex is saturated with sodium. ESP levels greater than 15 are associated with severely deteriorated soil physical properties and pH values o f 8.2 and above. However, it is also reported that growth of some sensitive plants is affected adversely even at a much lower level of exchangeable sodium percentage in black soils predominated with smechtite clay mineral (with an ESP values as low as 7). The SAR gives information on the comparative concentrations of Na^{+}, Ca^{2+} and Mg^{2+} in soil solutions. The SAR value of 13 for the solution extracted from a saturated paste is approximately equivalent to an ESP value of 15.

The alkali soils containing expanding type 2:1 clay minerals (vermiculite, montmorillonite) exhibit unfavourable physical properties for levels of ESP > 15, ES (exchangeable sodium) > 3.0 me $100g^{-1}$ or SAR > 15. In general the physical properties become increasingly unfavourable with increasing ESP but at a given level of ESP, physical properties are usually poorer in soils with expanding type 2:1 clay minerals, containing a low electrolyte concentration of salts capable of alkaline hydrolysis, *viz.*, sodium carbonate, sodium bicarbonate, sodium silicate, etc., than in soils with clay minerals of the non-swelling 1:1 type (Kaolinite) or mixed types, containing a high electrolyte concentration of neutral salts, *viz.*, sodium chloride or sodium sulfate. The ESP or SAR of alkali soils, in general, linearly and positively correlated with pH of the soil, whereas, there is no such relationship exist between electrolyte concentration and pH of the soil.

The soil texture and the tolerance of plants to ESP are two more factors, which are of practical importance in accessing the degree of deterioration as a consequence of ESP/SAR. The coarse textured soils exhibit less deterioration in physical properties as compared to the fine textured soils at a given ESP.

Slight to moderate sodic soils (ESP 15-30):

It is apparent from the data (Table 4.1.31) that ESP values varied between 11.96 to 31.98 in various pedons under study. Further examination of data revealed that ESP increased alongwith the depth of pedons examined. It can also be inferred from the data that the highest value of ESP (25.41 as a weighted mean) was recorded in pedon P_1 and the least value (16.60 as a weighted mean) was recorded in pedon P_2.

A critical examination of data revealed that SAR values lies between 2.70 to 11.51, and indicated that the SAR values recorded an increase with an increase in the ESP values. However, the magnitude of SAR recorded was much lower in contrast to the values registered for ESP. The ESP and SAR parameters of these soils when examined statistically indicates a positive correlation with a ‘r’ value of 0.513.

Moderate to highly sodic soils (ESP 30-50):

The values obtained for the ESP of soils of moderate to highly sodic soils are presented in table 4.1.31. Perusal of data indicated a wide variation and the values recorded for ESP ranged between 18.54 to 54.49. A relatively high value of ESP was registered in the soils of pedon P_7 and was followed by the soils of pedon P_{15}. It is also evident that, in general, the sodicity (ESP) increased as one proceeds down the depth in various pedons. The SAR values recorded for these soils ranged between 4.24 to 14.24, indicating a magnitude much lower in contrast to the values recorded for ESP. The SAR values of moderate to highly sodic soils, though, registered a change with a change in the ESP value of the soils in various pedons and the relationship when examined statistically indicated a positive correlation with a ‘r’ value of 0.433 for this group of soils.

(h) Gypsum requirement:

The quantity of gypsum required to reduce the exchangeable sodium percentage of a soil to an acceptable level is called gypsum requirement. Gypsum requirement depends on factors namely degree of soil deterioration, soil texture, degree of improvement desired, crops to be grown, etc. A fair correlation exists between pH of the soil and degree of sodium saturation.

Slight to moderate sodic soils (ESP 15-30):

An examination of data on gypsum requirement of slight to moderate sodic soils presented in table 4.1.31, indicated a range between 0.54 to 7.61 t ha^{-1}. It is further evident that a higher value of gypsum requirement was recorded for the bottom most horizon of the almost all the pedons under study. Like that of ESP, the gypsum requirement of slight to moderate sodic soils also increases with depth of the pedons examined. The relationship between ESP and GR when examined statistically for this group of soil indicated a positive correlation with a ‘r’ value of 0.877.

Moderate to highly sodic soils (ESP 30-50):

A perusal of data on gypsum requirement presented in table 4.1.31 indicated a wide variation and the values recorded ranged between 1.13 to 15.68 t ha^{-1}. Further, a critical examination of data indicated that the gypsum requirement increases alongwith depth of the pedons examined. The gypsum requirement recorded was of higher magnitude in soils of pedon P_7 with a weighted mean of 10.69 t ha^{-1} followed by the value recorded for the soils of pedon P_{18} and P_{11} with a weighted mean of 9.28 and 8.71 t ha^{-1}, respectively. The ESP and gypsum requirement of these soils when examined statistically indicates a positive relationship with a ‘r’ value of 0.850.

4.1.4 Nutrient Status:

The nutrient status of a soil is an indication of the soil fertility and one of the important factors, which determine the crop productivity of the soils.

Problematic soils are either deficient in nutrient status or the nutrient availability is inhibited by the antagonistic effect of the nutrient element present in excessive amount as soluble or exchangeable ions or both.

(a) Macronutrients:

Analysis of the soil for its major nutrients *viz.,* nitrogen, phosphorus and potassium, is a proven, practical method for evaluating the fertility status of the soils. The alkali and saline soils are usually low to medium in nitrogen, medium to high in phosphorus and high in potassium. The soils are rated as low (< 272 kg ha^{-1}), medium (272-544 kg ha^{-1}) and high (>544 kg ha^{-1}) in available N. Similarly these soils are categorized as low, medium and high in available P on the basis of critical values of < 12.4, 12.4-22.4 and > 22.4 kg ha^{-1}, respectively, while for available K the critical limits are as < 113, 113-280 and > 280 kg ha^{-1} for low, medium and high category, respectively (Arora, 2002).

Slight to moderate sodic soils (ESP 15-30):

It is apparent from the examination of data (Table 4.1.32) that the available nitrogen, phosphorus and potassium status varied from 84.30 to 348.70, 9.20 to 24.98 and 218.40 to 576.50 kg ha^{-1}, respectively in slight to moderate sodic soils of Chittorgarh district. The data on available nitrogen content showed a wide variation with a gradual decrease in its content as one traverse down the depth of various pedons. Further, from the examination of data it can be inferred that like nitrogen, the phosphorus content also registered a declining pattern as one proceeds down the pedon, except subsoil (45-60 cm) horizon of pedon P_4 and P_6 where a relatively higher value was observed as against the horizons just preceding. Based on weighted mean the available nitrogen status could be rated as low, while that of phosphorus could be rated as medium as per the limit prescribed in the literature except the nitrogen content observed for pedon P_4 which could be rated as medium. The available potassium content did not show any uniform trend when examined down the depth of various pedons, though, the potassium content was high in the soils of almost all the pedons examined.

Moderate to highly sodic soils (ESP 30-50):

A perusal of available macronutrients status elucidated in table 4.1.32, indicated a range of 64.30 to 398.90, 6.84 to 27.16 and 227.13 to 776.50 kg ha^{-1} for available nitrogen, phosphorus and potassium, respectively. Further, examination of data inferred that the nitrogen content decreased as one look down the depth in all the pedons examined. In general, the phosphorus content also registered a declining pattern as one proceeds down the pedons, leaving aside the surface horizon in almost all the pedons examined. As regard available potassium status of the soil, no uniform trend was noticed down the depth of various pedons. A further examination of data on weighted mean revealed that available nitrogen status could be categorized as low except of pedon P_7, where the status observed was medium, while, available phosphorus could be rated as medium. Likewise, the potassium status of the soil could be categorized as high except in soils of pedon P_3 and P_{17}, where it qualify for medium status.

(b) Micronutrients:

Micronutrients play a complex role in plant nutrition. The different crops have different requirements of micronutrients. The availability of micronutrients is affected by several factors, the important one are the pH, $CaCO_3$, organic carbon and parent material status of the soil. The soils, in general, are categorized as sufficient in available Zn, Cu, Fe and Mn if their DTPA extractable amounts in soils are above 0.8, 0.2, 4.5 and 3.0 ppm, respectively (Arora, 2002).

Slight to moderate sodic soils (ESP 15-30):

A perusal of data on available micronutrient cations status presented in table 4.1.33 revealed that the content of available zinc, iron, manganese and copper recorded a range between 0.31 to 1.14, 1.32 to 4.37, 2.76 to 10.53 and 0.29 to 1.46 mg kg^{-1}, respectively. All the micronutrient cations showed a wide variation and a gradual decrease in its content as one traverse down the depth of various pedons. Further, on the basis of weighted mean the slight to moderate sodic soils under study could be categorized as deficient for zinc (except P_2 and P_{19}) and iron, while, sufficient for manganese and copper from the view point of crop production.

Moderate to highly sodic soils (ESP 30-50):

An examination of data on available micronutrient cations status of moderate to highly sodic soils presented in table 4.1.33 revealed that available zinc, iron, manganese and copper content varied between 0.19 to 1.46, 0.98 to 4.12, 2.92 to 10.28 and 0.21 to 1.36 mg kg^{-1}, respectively. It is further evident that the higher values of micronutrient cations were noticed at the surface horizon which become progressively lower as one proceeds down the pedon in almost all the pedons. It can also be inferred from the weighted mean of micronutrient cations computed for different pedons that the moderate to highly sodic soils were also deficient in zinc (except P_{11} and P_{16}) and iron, while, sufficient in manganese and copper from the view point of crop production.

4.1.5 Nature and extent of salt-affected soils:

Salt-affected soils are the problems of individual localities and their formation and causes of development are of predominant considerations before being handled for their efficient management. Proper evaluation of the problem should be the first step to understand the cause of their formation and chalking out the technique for their reclamation and management. The terminology applied to the salt-affected soils varies from place to place. In the present investigation sodicity appraisal is suggested by Abrol *et al.,* (1988) and modified by Saxena and Verma (1995) were adopted to classify the sodic soils of district Chittorgarh. Two classes were identified in salt-affected soils of district Chittorgarh namely slight to moderate and moderate to highly sodic soils.

Presence of saline or alkali conditions affects the crop growth and productivity of lands. The management of such lands are different and area specific than normal and/or non-problematic soils. The boundaries of salt-affected soils drawn based on imprints of satellite imageries, when verified by field traversing and laboratory analysis indicated that a considerable area of normal soils were intermingled with salt-affected soils of various categories.

Based on the chemical and physico-chemical characteristics of the soils under study, the extent of distribution was measured with the help of curvimeter and expressed in hectares as well as percentage of total physiographic land. As per the revenue records available, the total physiographic and salt-affected area (including the unutilized barren land) of the district Chittorgarh is 10,35,733 and 75,914 ha, respectively. Based on our measurements using imprints of satellite imageries the total area engraved with salinity/sodicity problem comes out to be 23,615 ha in district Chittorgarh making 2.3 per cent of the total physiographic land.

(a) Slight to moderate sodic soils :

The soil categorized as slight to moderate sodic soils (ESP 15-30) exhibited pH value greater than 8.2. These soils were having ESP values ranging between 16.60 and 25.41 (as a weighted mean, Table 4.1.31) and pH value ranging between 8.2 to 9.3 (as a weighted mean, Table 4.1.27). These soils contain exchangeable sodium in a quantity sufficient to interfere with the growth of susceptible crop plants and do not contain appreciable quantities of soluble salts (ECe 0.71 to 3.85 dS m^{-1} as weighted mean, Table 4.1.27). Slight to moderate sodic soils under study constitute an area of 6,953.82 ha making 0.7 per cent of total physiographic land and 29.4 per cent of the salt-affected land of the district Chittorgarh (Fig.4.2 and 4.3). Further, these soils are mainly distributed in tehsil Kapasin, Rashmi and Begun (Fig.4.1).

(b) Moderate to highly sodic soils:

In this category of salt-affected soil areas adjoining to 14 pedons could be included. These soils contain sufficient ESP (30-50) to interfere with the growth of most of the crop plants. The pH of these soils ranged between 8.8 to 9.8 as a weighted mean, while, the ESP values lies between 32.01 to 42.21 as a weighted mean (Table 4.1.31), however, these soil do not contain any appreciable quantity of soluble salts (ECe 1.34 to 3.63 dS m^{-1} as weighted mean, Table 4.1.27)

Moderate to highly sodic soils constitute an area of 16,661.18 ha in the district making 1.6 and 70.6 per cent of total physiographic and salt-affected land, respectively (Fig. 4.2 and 4.3). Such types of soils are distributed in tehsil Dungla, Kapasin, Rashmi, Pratapgarh and Begun of district Chittorgarh (Fig.4.1).

4.2 TAXONOMIC CLASSIFICATION OF SOILS:

Based on morphological, physical and chemical characteristics of the soils, diagnostic characters have been identified which forms the basis to classify the soils of the study area according to soil taxonomy (Soil Survey Staff, 1998). A systematic classification of the soils is of immense importance to help transfer of agro-technology and add to existing knowledge for the benefit of planners, agricultural workers, engineering workers, scientists and technologists. Details of prominent features are discussed in this section.

4.2.1 Diagnostic Surface Horizons:

Ochric epipedon : The surface soils of the study area are light in colour (10 YR 4/2 M to 10 YR 4/4 M), contains little organic carbon (0.04 to 0.79 per cent) and becomes hard when dry. Though the value of chroma are sometimes lower than required for ochric epipedon, their chances of falling under mollic or umbric epipedons are unlikely due to low value of organic matter and has less than 15 per cent calcium carbonate. Therefore, the surface horizons of these soils are grouped under ochric epipedon.

4.2.2 Diagnostic Subsurface Horizons:

(A) Calcic horizon : According to Keys to Soil Taxonomy (Soil Survey Staff, 1998), a calcic horizon must have a thickness of 15 cm or more, should not have a petrocalcic horizon, must have a minimum of 15 per cent calcium carbonate and should have 5 per cent or more by volume of secondary carbonate equivalent in the form of soft powdery lime than the underlying horizons. In the study area, secondary lime accumulation continues down the depth of the profile, but it may be of geogenic origin in majority of the pedons under examination (Sehgal and Stoops, 1972; Kalbande *et al.*, 1992 and Balpande *et al.*, 1996). Therefore, considering the above characteristics, calcic horizon is observed in almost all the pedons under study.

(B) Cambic horizon : A diagnostic subsurface horizon that has a texture of loamy very fine sand or finer and contains some weatherable minerals. It is characterized by alteration in colour, structure, texture, etc. and is exhibited in almost all the pedons under study except pedon P_6 and P_{10}.

4.2.3 Classification:

The taxonomic classification of the salt-affected soils occurring in district Chittorgarh was worked out based on morphological, physico-chemical properties of soils (Soil Survey Staff, 1998). The soils of slight to moderate sodic group were keyed out under Inceptisol order and further under Ustepts suborder that have an Ustic moisture regime except pedon P_6 which keyed out under Entisols order and further under Fluvents suborder because of absence of cambic horizons and no further development of these soils beyond an ochric epipedon. The soils of pedon P_6 do not have a calcic horizon, though the soil of pedon P_6 is calcareous in nature and thus key out as Ustilfluvent due to ustic moisture regime at group level. Further, these soils qualify to the central concept of Ustifluvents and thus may be classified at family level as : Loamy, mixed (calcareous), hyperthermic, *Typic Ustifluvents*.

Under Ustept, calcic horizons was identified in pedon P_1, P_2, P_9 and P_{19}. Further, these soils were qualify for the central concept of Calciustepts and thus keyed out under *Typic Calciustepts* at subgroup level. For family level classification, textural class, mineralogical class and temperature regime have to be included and the soils of pedons P_1, P_2, P_9 and P_{19}, may thus be classified to the family level as: Loamy, mixed, hyperthermic, *Typic Calciustepts*. The soils of pedon P_4 do not have a calcic horizon, though the soils of pedon P_4 is calcareous in nature and thus key out as Haplustepts at group level. Further, these soils qualify to the central concept of Haplustepts and thus may be classified as *Typic Haplustepts* to the subgroup level. At family level these soils may be classified as: Loamy, mixed (calcareous), hyperthermic, *Typic Haplustepts*.

Salt-affected soils of the moderate to highly sodic group keyed out under Inceptisols order except pedon P_{10} which keyed out under Entisols. Presence of ochric epipedon and ustic soil moisture regime, this (P_{10}) may be classified as Ustorthents to the great group level. Due to presence of a lithic contact within 50 cm of the mineral soil surface, this may be classified as *Lithic Ustorthents* at subgroup level. Further, this soil may be classified to the family level as: Fine loamy, mixed (calcareous), hyperthermic, *Lithic Ustorthents*. Taking into consideration the ustic soil moisture regime the soils under moderate to highly sodic soil group (except pedon P_{10}) were keyed out as Ustepts to the suborder level of Inceptisols. At great group level the soils of pedon P_5, P_{11}, P_{13}, P_{15}, P_{17}, P_{18} and P_{20} were keyed out as Calciustepts because they possess calcic horizon. Further, these soils qualify to the central concept of Calciustepts and thus may be classified as *Typic Calciustepts* to the subgroup level. At family level these soils are classified as:

P_5, P_{11} and P_{18} : Fine loamy, mixed, hyperthermic, *Typic Calciustepts*

P_{13}, P_{15}, P_{17} and P_{20} : Loamy, mixed, hyperthermic, *Typic Calciustepts*

The soils of pedon P_3, P_7, P_8, P_{12}, P_{14} and P_{16} do not have a calcic horizon though the soils of these pedons are calcareous in nature and thus keyed out as Haplustepts at great group level. Further, these soils qualify to the central concept of Haplustepts and thus may be classified as *Typic Haplustepts* to the subgroup level. At family level these soils are classified as: P_{14} : Fine loamy, mixed (calcareous), hyperthermic, *Typic Haplustepts.*

P_3, P_7, P_8, P_{12} and P_{16} : Loamy, mixed (calcareous), hyperthermic, *Typic Haplustepts.*

4.3 GROUND TRUTH:

The accurate and precise identification of the saline and alkali soils and the diagnosis of the causes of the low productivity of otherwise potentially productive lands, are of prime significance for any effective measures that can be undertaken for their economic exploitation. The alkali soils can be visually and qualitatively identified and distinguished from saline and normal soils in the field by some visual observations. Effective and accurate identification of area adjoining to salt-affected soils, ground truth (0-15 cm) were collected from the other fields of the study area to establish correlation with the soils of pedon, if any.

For the ease of comparison of results of the soil samples analyzed from 71 ground truth were grouped according to salinity and sodicity (Table 4.3.2 and 4.3.3) as suggested by Soil Survey Division Staff (1995). Categorization of ground truth based on salinity appraisal (Table 4.3.2) clearly indicated that almost 93 per cent ground truth samples comes under non-saline soils, 6 per cent in very slightly saline soils and 1 per cent under slightly saline soils.

Table 4.3.2 Categorization of ground truth based on salinity appraisal

S. No.	Class	ECe (dS m^{-1})	No. of ground truth
1	S_1 Non saline	< 2.0	66
2	S_2 Very slightly saline	2.0-4.0	4
3	S_3 Slightly saline	4.0-8.0	1
4	S_4 Moderately saline	8.0-16.0	None
5	S_5 Strongly saline	> 16.0	None

In general, the ECe values ranged between 0.39 to 4.45 dS m^{-1} (Table 4.3.1), which also prove their categorization as non-saline soil. However, when we categorize the ground truth samples under study based on sodicity appraisal (Table 4.3.3) indicated that 87 per cent (62 samples) comes under none to slight sodic soil, 12 per cent (8 samples) under slight to moderate sodic soils and 1 per cent (1 sample) under moderate to highly sodic soils. Perusal of the data on ESP presented in table 4.3.1, indicated values ranged between 5.26 to 22.85 per cent except one sample (Sample No.54) which show exceptionally high value of ESP (38.04 %).

Table 4.3.3 Categorization of ground truth based on sodicity appraisal

S. No.	Class	ESP	No. of ground truth
1	S_1 None to slight	< 15	62
2	S_2 Slightly to moderate	15-30	8
3	S_3 Moderate to high	30-50	1
4	S_4 High to very high	> 50	None

Perusal of data pertaining to organic carbon content of ground truth under investigation (Table 4.3.1) indicated a range between 3.75 to 7.65 g kg^{-1}, except ground truth no.1 which showed exceptionally high value of organic carbon (8.80 g kg^{-1}). It is apparent from the examination of data elucidated in table 4.3.1 that calcium carbonate constituted a significant part of the ground truth under study and ranged between 12.50 to 238.0 g kg^{-1} indicating the calcareous nature of the ground truth leaving beside few exceptions. A further perusal of data on CEC of the soil revealed that the CEC values varied between 14.37 to 27.68 cmol (p+) kg^{-1} in different ground truth collected for the study. The CEC of ground truth is positively correlated with clay content of ground truth. The textural class of these ground truth varied from sandy loam to clay loam.

4.4 CHEMICAL COMPOSITION OF WELL WATER:

Crop production in the arid and semi-arid regions is dependent on irrigated agriculture. The irrigation water should not contain soluble salts in amount that will be harmful to the plants or have an adverse effect on the soil properties, is a pre-requisite for crop production in the hot and dry climates of these regions. Moreover, in these areas water of good quality is usually not available in sufficient quantities to satisfy the water requirements of all the crops grown. Under these conditions the farmers are forced to use the irrigation water with high quantities of dissolved salts and/or RSC, invariably accompanied with yield reduction in most of the crops being grown. Indiscriminate use of such water can often lead to crop failures and/or development of the saline or sodic soils, which in turn, require expensive treatment to revert them productive again. On the other hand saline and/or sodic water if skillfully used, can contribute to the successful production of a variety of crops particularly on light textured soils.

Detailed chemical analysis of irrigation water from district Chittorgarh are presented in table 4.4.1. The mean value of each constituent of irrigation water sampled from the areas has also been presented.

Slight to moderate sodic soils (ESP 15-30):

The detailed analysis of water samples collected from the area associated with slight to moderate sodic soils of Chittorgarh district are presented in table 4.4.1. An examination of data revealed that all the water samples so collected were alkaline in reaction with a pH value ranging between 7.35 to 8.55. The EC values of these waters ranged between 0.95 to 4.37 dS m^{-1} with a mean value of 2.01 dS m^{-1}. Further, it is also evident from the examination of data that among the cations sodium is most predominant followed by calcium, magnesium and potassium ($Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$). The respective mean value of their concentrations observed were 13.9, 3.5, 2.4 and 0.7 me l^{-1} for sodium, calcium, magnesium and potassium, respectively.

In case of anions, chloride is most predominant followed by bicarbonate, sulphate and carbonate with a range varied between 2.4 to 28.8, 5.4 to 10.4, 0.4 to 3.6 and traces to 2.2 me l^{-1}, respectively. The respective mean values computed were 11.1, 7.3, 1.8 and 0.9 me l^{-1}. The fluoride content ranged between 0.48 to 4.43 ppm with a mean value of 2.41 ppm, indicating a higher build up of fluorine in this region. Further, it was also observed from the data that boron and nitrate content ranged between 0.56 to 3.62 and 6.0 to 10.8 ppm with a mean value of 1.36 and 8.1 ppm, respectively, indicating a comparatively higher build up of these anions in the region.

Moderate to highly sodic soils (ESP 30-50):

Perusal of data on the composition of irrigation water associated with areas having moderate to highly sodic soils presented in table 4.4.1 revealed that the pH value ranged between 7.37 to 8.67 indicated their alkaline nature. EC values of the water samples varied between 0.43 to 5.43 dS m^{-1}, with mean value 1.62 dS m^{-1}. A thorough examination of data from the table revealed that sodium predominated among the cations followed by calcium and magnesium with a respective value registered between 2.6 to 32.1, 0.8 to 13.0 and 0.4 to 10.4 me l^{-1}. The potassium ion positioned at last with a range between 0.2 to 2.0 me l^{-1}. Further, among the anions chloride dominated over sulphate followed by bicarbonate and carbonate ions with a respective range recorded in the tune of 1.2 to 36.8, 0.4 to 11.4, 1.2 to 9.8 and traces to 1.8 me l^{-1}. The fluoride content observed ranged between 0.38 to 3.73 ppm with a mean value of 1.87 ppm, indicating a lower build up of this ion as compared to the irrigation waters of the area having slight to moderate sodic soils. It was also inferred from the examination of data that boron and nitrate content in irrigation waters associated with moderate to highly sodic soils ranged between 0.64 to 5.72 and 6.6 to 14.5 ppm with a mean value of 1.61 and 8.2 ppm, respectively, indicating a higher build up of these ions in the region.

4.5 ALTERNATE AND SUSTAINABLE LAND USE PLANNING:

Soils under study have been rated for the five crops of *kharif* (sorghum, soybean, maize, pearl-millet and cotton) and three crops of *rabi* (wheat, barley and mustard) for suitability evaluation. Land suitability for different crops and land quality ratings as suggested by Sys *et al.* (1991) with slight modification (NBSS & LUP, 1994, 1998) are presented in Appendix-I.

Land qualities and suitability for different crops as evaluated for the area under present study are presented in table 4.5.1 and 4.5.2, respectively. The inferences drawn based on the land qualities and suitability ratings are described in this section.

Slight to moderate sodic soils (ESP 15-30):

The soils of slight to moderate sodic group in the present study are moderately suitable on account of limitations imposed by fertility (O.C. < 0.4 per cent) for wheat, sorghum and pearl-millet and sodicity (ESP 20 to 35) for wheat and sorghum. Further, this group of soils are marginally suited to soybean, cotton, barley and mustard due to major limitation of sodicity (for soybean and mustard), fertility (for soybean and cotton) and $CaCO_3$ (for soybean). The soils under examination found non-suitable for maize due to major limitation exhibited by fertility and sodicity.

Moderate to highly sodic soils (ESP 30-50):

The soils under investigation are rated moderately suitable for pearl-millet and wheat on account of limitations imposed by fertility and sodicity. However, they are marginally suitable for sorghum, barley and cotton due to major limitations imposed by sodicity and fertility. Further, these soils are not suitable for soybean, maize and mustard because of major limitation imposed by sodicity and fertility.

4.6 CONSTRAINTS ANALYSIS FOR SUSTAINABLE AGRICULTURE:

Indicators of soil sustainability, such as bulk density, texture, structure, available water capacity, pH, EC, ESP and organic C are compared with the limits as described by Lal (1994) (Appendix-II) to understand the severity of constraints for sustainability. These will serve as base line indicators for future planning and also determine the crop yield and response to the management practices adopted. The indicators observed in the present investigation based on morphological and laboratory studies are presented in table 4.6.1 with weighting factors (scoring).

(A) Bulk density : Bulk density of soil govern soil compaction, root growth and infiltration of water. In present study the bulk density observed ranged between 1.42 to

1.62 Mg m^{-3}, registered an extreme limitation for sustainability in most of the soils examined.

(B) Texture : The soils under investigation registered a range of texture between clay loam to sandy clay loam and thus could be placed in the category of moderate limitations from the view point of sustainability. Because of moderate limitation, these soils suffer moderately on account of crusting, gaseous diffusion and infiltration, creating a problem of reducing/anaerobic condition in lower depth.

(C) Structure : In general, the structure observed for the soils under study was moderate sub-angular blocky offering a moderate limitation in their workability and management.

(D) Consistency : Salt-affected soils of district Chittorgarh showed, in general, a friable consistency, placing the soil with moderate level of limitations, indicating some difficulty in workability and problem of seedling emergence and root penetration.

(E) Plant available water capacity (PAWC) : Like that of other physical parameters, the PAWC was also a constraint offering moderate limitations (PAWC 80 – 200 mm) in both slight to moderate and moderate to highly sodic soils. As a consequence the crop may face frequent drought injury in the soils under study of district Chittorgarh.

(F) pH : Salt-affected soils of district Chittorgarh exhibited a severe limitation on account of soil pH (> 8.2). The high pH of these soil may affect the nutrient dynamics in the soil through creating an imbalance in the nutrient availability, which ultimately results in drastic reduction of soil productivity.

(G) Electrolyte concentration : The limitation on account of electrical conductivity of the soil did not exhibit any problem. Therefore, these soils did not show any adverse effect due to salinity. Specific ion toxicity may occur due to high level of sodium and nutrient imbalance also causes the reduction in crop yields on these soils.

(H) ESP/SAR : The SAR values observed were < 10 in all the soils examined, giving an impression that the soils could be categorized with no limitations. However, SAR has not been considered as a fair indicator and thus we have taken ESP as an indicator of sodicity rather than SAR.

On account of exchangeable sodium percentage a slight level of limitations were recorded in slight to moderate sodic soils (ESP 15-30), however, in moderate to highly sodic soils (ESP 30-50) moderate limitations were registered. Because of slight to moderate limitations posed on account of ESP by these sodic soils in the region a slight to moderate deterioration in soil physical properties will be encountered by the crops grown.

(I) Organic carbon : Salt-affected soils of district Chittorgarh showed an extreme level of limitation on account of organic carbon (< 0.4 %) content under situation of semi-arid (dry) conditions which indicates low fertility status of the soils.

Table 4.4.1 Chemical composition of irrigation water samples collected from area adjoining to salt affected soils of district Chittorgarh

S. No.	pH	EC (dSm^{-1})	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$	F^{-}	B	NO_3^{-}	adj. SAR	RSC ($me\ l^{-1}$)
			($me\ l^{-1}$)								(ppm)				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Slight to moderately sodic soils (ESP 15 – 30)															
1	7.66	3.92	7.2	7.4	23.5	1.2	Tr	8.8	27.6	2.7	3.64	0.64	6.8	24.36	-5.8
2	7.53	4.37	6.8	5.6	29.8	1.6	0.4	10.2	28.8	3.6	3.67	0.76	6.0	33.52	-1.8
6	7.74	2.23	4.4	2.4	14.3	0.9	0.8	8.2	11.6	2.8	1.67	0.56	7.4	19.42	2.2
7	8.14	1.33	2.4	1.2	9.4	0.4	1.0	6.8	4.8	1.4	1.85	0.60	7.2	16.12	4.2
9	8.42	2.08	2.6	1.2	17.8	0.7	1.8	6.8	10.4	2.7	1.64	0.92	9.3	28.38	4.8
10	8.47	2.05	1.6	1.4	17.6	0.5	1.2	7.0	11.6	1.8	3.76	1.24	9.6	30.28	5.2
11	8.55	1.89	0.8	0.4	16.9	0.5	2.2	6.8	9.6	0.4	4.43	1.36	9.3	39.51	7.8
12	7.85	1.28	4.2	2.0	6.4	0.4	1.2	7.2	3.6	1.4	3.84	1.36	10.8	9.10	2.2
13	7.87	1.01	2.4	1.8	5.6	0.2	1.0	6.4	2.8	0.7	2.93	1.16	9.6	8.88	3.2
23	7.96	3.73	9.0	5.8	21.7	1.4	0.6	10.4	21.6	5.3	1.57	3.32	7.8	23.14	-3.8
24	8.22	0.96	1.8	1.4	6.8	0.3	0.6	5.8	2.4	1.6	1.43	3.62	7.6	11.34	3.2
26	8.13	1.33	1.4	0.8	11.1	0.7	0.8	6.8	14.8	0.8	2.18	1.08	7.0	22.19	5.4

43	7.41	0.95	2.6	1.2	6.1	0.2	1.2	5.4	2.8	0.9	0.48	1.16	7.6	10.32	2.8
44	7.35	1.04	2.0	0.8	7.7	0.4	0.8	6.0	2.8	1.6	0.62	1.32	7.1	14.70	4.0

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Moderate to highly sodic soils (ESP 30 –50)															
3	7.63	1.49	2.2	2.6	9.3	0.7	Tr	9.2	3.6	1.4	3.53	0.68	6.3	15.00	4.4
4	7.84	1.24	2.4	2.0	7.6	0.5	0.4	8.8	2.8	1.7	1.76	2.14	7.0	12.82	4.8
5	7.76	0.89	1.8	0.8	6.3	0.3	0.8	6.2	1.2	0.9	1.79	1.12	6.7	11.59	4.4
8	8.06	0.66	1.4	0.4	4.5	0.2	Tr	5.4	1.2	0.4	1.48	1.84	8.9	9.48	3.6
14	7.42	3.78	11.2	7.4	18.3	1.2	1.8	9.8	22.8	5.1	0.57	0.92	11.4	18.60	-7.0
15	7.53	5.43	13.0	6.8	32.1	2.0	0.6	6.4	36.8	11.4	0.81	1.24	7.4	28.62.	-12.8
16	7.74	1.36	2.4	1.8	8.9	0.7	0.8	8.2	3.6	1.7	1.89	1.60	5.6	14.74	4.8
17	8.09	1.51	2.8	1.2	11.3	0.5	0.8	7.4	6.8	0.7	2.86	1.72	6.4	18.42	4.2
18	7.99	1.03	2.0	0.8	7.8	0.4	0.4	6.2	3.2	1.4	2.73	0.64	6.0	13.88	3.8
19	8.68	0.63	1.8	0.8	3.9	0.2	0.8	3.2	2.0	0.4	1.76	1.28	7.8	6.50	1.4
20	8.13	1.10	1.4	0.4	9.6	0.4	1.0	4.8	4.8	0.6	3.73	1.16	7.2	19.19	4.0
21	8.35	1.04	1.4	1.0	7.1	0.5	1.0	6.4	2.8	0.8	2.31	3.44	6.8	13.67	5.0
22	8.04	2.04	3.8	2.4	13.0	0.9	1.8	8.6	7.6	3.1	1.21	3.28	7.4	18.47	4.2
25	7.76	1.28	2.6	1.2	8.7	0.8	0.4	6.8	5.2	0.4	1.64	0.96	6.8	14.60	3.4
27	7.87	2.40	4.2	2.2	17.7	1.0	0.4	8.2	31.6	1.4	1.52	1.16	10.5	23.74	2.2
28	7.37	4.33	8.8	8.4	24.1	1.4	Tr	8.0	31.6	5.1	0.39	0.96	11.3	23.95	-9.2
29	8.09	1.19	0.8	0.4	9.8	0.3	1.0	6.2	4.4	1.7	1.57	1.12	14.5	24.19	6.0
30	8.02	0.68	1.2	0.6	5.2	0.2	0.8	3.2	2.8	0.4	1.62	1.48	11.9	10.17	2.2
31	8.18	1.00	2.4	0.8	7.6	0.4	1.0	6.4	3.2	0.9	2.18	1.56	12.1	13.27	4.2
32	8.44	2.40	4.0	2.8	16.1	0.7	0.6	7.2	14.8	3.1	3.06	1.28	10.1	21.87	1.0
33	8.23	1.28	1.0	0.8	11.4	0.5	1.2	6.2	5.2	1.4	2.78	0.72	7.9	24.26	5.6
34	8.22	0.89	1.6	0.8	6.8	0.2	1.8	4.2	2.4	2.3	1.93	1.04	6.4	13.08	3.6
35	8.19	1.17	1.4	0.4	9.8	0.3	1.2	6.6	2.8	1.4	3.58	0.84	6.8	20.86	6.0
36	8.01	1.64	1.2	0.6	13.4	0.7	1.2	6.4	7.6	2.8	3.17	0.76	7.1	28.50	5.8
37	8.67	1.13	1.8	1.4	8.3	0.4	0.6	7.2	2.8	1.7	2.35	1.58	7.0	14.49	4.6
38	8.02	1.25	1.4	1.6	8.2	0.5	0.8	6.4	4.8	1.9	2.24	1.76	7.7	14.78	4.2

39	8.48	1.44	2.8	1.8	8.7	0.7	0.8	7.6	6.4	0.4	1.96	1.88	7.3	13.92	3.8
40	8.39	1.39	3.2	3.0	7.4	0.5	1.2	7.2	5.2	2.3	1.33	5.72	8.4	10.87	2.2
41	7.60	4.22	12.8	10.4	17.4	1.6	Tr	7.6	26.4	9.7	0.45	1.70	8.2	15.36	-15.6
42	8.12	1.06	2.4	1.2	7.9	0.3	0.8	5.8	3.6	1.4	0.54	1.12	8.9	13.38	3.0
45	8.36	0.43	0.8	1.2	2.6	0.2	1.4	1.2	1.8	0.6	0.38	1.08	6.8	4.16	0.6
46	7.72	0.61	1.8	0.6	3.9	0.3	0.8	3.6	1.2	0.4	0.84	4.88	6.3	6.80	2.0

Tr. = Traces

5. DISCUSSION

The results of the investigation entitled "Characterization of salt-affected soils and water resources of sub-humid southern plains of Rajasthan" presented in previous chapter, exhibited a set of distinct morphological, physical and chemical characteristics in response to relationship established as a consequence of micro-climatic variations. The variability in the micro-climate brought some restrictions over the activity of pedogenic forces, resulting in the variation in soil properties. The results of the present study are discussed in this chapter in light of the available literature under the following sub-heads:

5.1 Morphological features
5.2 Physical characteristics
5.3 Chemical characteristics
5.4 Nutrient status
5.5 Ground truth
5.6 Categorization of well water
5.7 Alternate and sustainable land use planning
5.8 Reclamation and management strategies
5.9 Sustainability assessment

5.1 MORPHOLOGICAL FEATURES:

5.1.1 Soil Colour:

Morphological features of the various pedons under study presented in table 4.1.4 to 4.1.23, indicated a very dark grayish (10 YR 3/2 M) to light brownish gray (10 YR 6/2 M) colour. Dark colour is attributed to chelation and complexation of organic colloids on the surface of clay particles (Dudal and Eswaran, 1988) or due to discrete clay minerals (Buhmann and Schoeman, 1995). The removal of free iron under reducing conditions impart the soil mineral grain to appear gray (Buol *et al.*, 1998).

In general, salt-affected soils of district Chittorgarh registered brown to dark brown colour in surface and dark grayish brown to light yellowish gray colour in subsurface horizons. The colour variation in the soils of substratum in contrast to surface horizons evidenced higher value and lower chroma which can be attributed to the presence of high amount of free calcium carbonate (Table 4.1.27) and to the saturation and reduction coupled with mixing of organic matter and soil matrix with carbonate (Randall *et al.*, 1996) and/or transportation through the process of illuviation. Similar findings were also been reported by Mathur *et al.* (1968), Mehta *et al.* (1969), Veer Pal (1976) and Sharma *et al.* (2004).

5.1.2 Soil Texture:

The texture of salt-affected soils in district Chittorgarh ranged between sandy clay loam to clay loam with some exception for the soils of moderate to highly sodic soils where somewhat heavier texture was observed. Further, it was also observed that soil texture becomes heavier (improved) as one proceeds down the depth of pedons. A wide variation in texture suggests transportation and accumulation of alluvium from short distances over the years on the original parent material. The other factor which might be responsible for such variations may be due to the differences in weathering activity in different pedons (Sharma *et al.,* 1968; Darra *et al.,* 1970; Kumar and Kumar, 1993 and Sharma, 2000).

5.1.3 Structure:

A critical examination of data presented in table 4.1.4 to 4.1.23 revealed more or less uniformity in structure in all the group of soils examined. The most dominant structure recorded was sub-angular blocky with weak to moderate strength indicating a process of profile development (Srinivasan, 1976 and Kumar and Kumar, 1993). The clay content, calcium carbonate and to some extent organic matter (Miller and Donahue, 1982) might have acted as cementing agent for the development of sub-angular blocky structure. However, a massive soil structure in lower depth of the majority of pedons (P_1, P_2, P_4, P_5, P_6, P_7, P_8, P_9, P_{12}, P_{13}, P_{16}, P_{17}, P_{18}, P_{19} and P_{20}) was registered. The soils of these pedons were relatively higher in calcium carbonate content (Table 4.1.27) accompanied by prevalence of moist conditions (Table 4.1.26) in the sub-soil layers might have resulted in lack of development and/or destruction of the soil structures (Mathur *et al.*, 1968; Ballinfante *et al.*, 1974 and Sharma, 2000). The observation made by Mathur *et al.* (1968), Kolarkar *et al.* (1974), Mondal and Sharma (1997) and Sharma *et al.* (2004) for salt-affected soils of Rajasthan are in close conformity with the findings of the present investigation.

5.1.4 Effervescence:

An examination of data on morphological features indicated that most of the salt-affected soils of district Chittorgarh produced effervescence when subjected to treatment with dilute HCl. Further, the effervescence become violent as one proceeds down the depth of pedons indicating an increase in the content of calcium carbonate as is also evidenced by the content of calcium carbonate observed (Table 4.1.27). This may be ascribed to the presence of carbonaceous material in the parent rock which is least affected by pedogenic activities (Verma, 1995 and Singh, 1999) and/or downward movement and precipitation of calcium as calcium carbonate in lower depths (Kanwar and Sehgal, 1962). Further, calcium carbonate concretions of different sizes were observed, especially in the sub-surface horizons creating severe physical impediment for capillary movement of moisture within the profile and poor/restriction of root growth (West *et al.,* 1988; Sharma *et al.,* 1996 and Pal *et al.,* 1999). Less annual rainfall (850 mm) in the study area, restricted the leaching of bicarbonate in soils because of poor hydraulic conductivity (Balpande *et al.,* 1996) and therefore, precipitation of carbonate occurs throughout the pedon depth (Table 4.1.27) indicating accumulation of pedogenic carbonate (Pal *et al.,* 1999).

5.2 PHYSICAL CHARACTERISTICS:

5.2.1 Bulk Density:

The bulk density of salt-affected soils of district Chittorgarh, varied from 1.41 to 1.62 Mg m^{-3} (Table 4.1.24). Higher values of bulk density are indicative of the unfavourable conditions for profuse root development, water intake and activity of microflora. Comparatively lower values have been recorded in surface soil layer which contains higher amount of organic matter. The bulk density values in slight to moderate and moderate to highly sodic soils showed an increasing trend alongwith depth of pedon examined. The bulk density values ranges between 1.42 to 1.62 and 1.41 to 1.62 Mg m^{-3} for slight to moderate and moderate to highly sodic soils, respectively. This could be attributed to clogging of pores by dispersed clays in subsoil layer (Mathan and Mahendran, 1994) and reduction of organic carbon with depth (Yeresheemi *et al.,* 1997).

5.2.2 Particle Density:

The particle density values varied from 2.46 to 2.73 Mg m^{-3} (Table 4.1.24) in various horizons of slight to moderate and moderate to highly sodic soils. Almost identical values were obtained for particle density in different groups of salt-affected soils of district Chittorgarh. A lower magnitude of variation in particle density suggests no significant variation in mineralogical makeup of the soils. Yeresheemi *et al*. (1997) and Sharma (2000) also observed a little variation in particle density within or among the profiles in salt-affected soils of UKC (Upper Krishna Command) area of Karnataka and Rajasthan, respectively.

In general, a higher value of particle density was recorded in subsurface horizons of the pedons studied, which can be attributed to an accumulation of secondary oxides of iron (Veer Pal, 1976) and relatively lower proportion of organic matter leading to an increased weight of soil solid (Veer Pal, 1976; Sangwan, 1978; Yeresheemi *et al.,* 1997 and Sharma, 2000).

5.2.3 Porosity:

The total porosity values of salt-affected soils under study ranged between 37.96 to 45.18 per cent (Table 4.1.24). In general, the porosity percentage decreased from surface to subsurface horizons of pedons under investigation. The lower magnitude of pore space in the subsurface horizons could be ascribed to the reduction in organic carbon content (Table 4.1.27), compaction by cementing agents and high degree of sodium saturation which has the ability to disperse the clay and on downward movement fills the micropores, leading to the formation of compact horizon down the depth of pedon (Sangwan¸1978; Kumar and Kumar, 1993; Balpande *et al.,* 1996; Yeresheemi *et al.,* 1997 and Sharma, 2000).

5.2.4 Particle Size Distribution:

The texture of slight to moderate sodic soils of district Chittorgarh varied between sandy clay loam to clay loam with an exception of bottom most horizon of P_4, where clayey texture was observed (Table 4.1.25), while, in moderate to highly sodic soils it ranged between sandy loam to clay loam with an exception of lower horizons in pedon P_5, P_{11}, P_{14} and P_{18}, which showed a clayey texture.

Further, a perusal of data on particle size distribution presented in table 4.1.25 showed that the sand percentage varied between 28.9 to 67.3, while silt fraction ranged between 6.6 to 41.6 per cent. Though, the sand fraction in soils of study area, in general, exhibited an irregular trend along the depth of pedon. However, some of the pedons (P_5, P_{11}, P_{13} and P_{16}) exhibited a decreasing trend of sand down the depth. Similarly, silt fraction also did not register any specific trend along the depth of pedons examined. The irregular distribution of sand and silt fraction in different pedons under study might be due to differential deposition and erosion cycles alongwith parent material discontinuity. Moreover, regional topography is basin type (Mathur *et al.,* 1968) coupled with variation in weathering intensity may have also lead to such formation. Veer Pal (1976); Sidhu *et al.* (1976); Sangwan (1978); Jha and Sharma (1989); Qureshi *et al.* (1996); Ray and Reddy (1997); Bhaskar and Nagaraju (1998); Challa *et al.* (2000); Nayak *et al.* (2000) and Sharma (2000) also observed irregular distribution of these fractions due to parent material discontinuity. Though, the clay content of the investigated area ranged between 17.6 to 42.8 per cent, however, in pedon P_{11} at the lower depth (beyond 45 cm) an invariably high value to the extent of 44.7 to 60.8 per cent of clay was noticed. It was further inferred from the examination of data that clay fraction, in general, was more concentrated in subsurface layers of various pedons. Clay accumulation in subsurface horizons may be due to mass movement of fine clay (Pal *et al.,* 1999). The movement of clay to the lower layers has been enough to contribute an appreciable textural change sandy loam/sandy clay loam to clay loam in lower depths of pedons under study. Sharma *et al.* (1968); Dubey and Sharma (1988); Kumar and Kumar (1993); Sahu and Dash (1993); Yeresheemi *et al.* (1997); Challa *et al.* (2000) and Sharma *et al.* (2004) have also reported movement of clay in subsurface layers of pedon in salt-affected soils.

Further, these soils are characterized by a high sand/silt ratio, ranging between 0.8 to 9.5 (Table 4.1.25). Smith and Wilding (1972); Sidhu *et al.* (1976) and Ray *et al.* (1997)

reported that if difference of sand/silt ratio is more than 0.20 between adjacent horizons it indicates lithological discontinuity. The differences of greater than 0.2 of sand/silt ratio between adjacent horizons in the present investigation was extensive in most of the pedons under study indicating lithological discontinuity in these soils. This may be due to the influence of alluvial material transported by the local stream/ephemeral and deposited in this region. Similar results have also been reported by Jha and Sharma (1989) for the salt-affected soils of North Bihar, Challa *et al*. (2000) for the salt-affected soils of Ahmednagar and Akola district of Maharashtra and Sharma (2000) for the salt-affected soils of district Bhilwara.

5.2.5 Water Retention Characteristics:

The water retained by soils at different tensions presented in table 4.1.26, indicated that the water held at -0.033 MPa tension ranged between 0.17 to 0.41 and 0.20 to 0.39 m^3 m^{-3} for slight to moderate and moderate to highly sodic soils, respectively. While amount of water retained at -1.5 MPa tension ranged between 0.04 to 0.24 and 0.08 to 0.21 m^3 m^{-3} for slight to moderate and moderate to highly sodic soils, respectively. Further, when compared with surface soil layers in majority of pedons the values of water retention observed for the subsurface soil layers were higher at both the soil water tensions examined. The moisture retention at -0.033 MPa tension was found to be a function of mechanical components of the soil in the present investigation as is manifested by existence of a positive correlation with silt (r = 0.29) and clay (r = 0.58), and negative correlation with sand (r = -0.51) (Diwakar and Singh, 1992; Yadav and Vyas, 1998 and Sharma, 2000). However, at this tension (-0.033 MPa) the moisture content is poorly correlated with organic carbon (r = 0.14) and soluble salts (r = 0.21) content of the soil (Yadav *et al*., 1995; Bhaskar and Nagaraju, 1998 and Sharma, 2000).

Similarly, moisture retention at -1.5 MPa was also positively correlated with clay (r = 0.41) and silt + clay (r = 0.45), while, negatively correlated with sand (r = -0.39). Further, the water retention at this tension was poorly correlated with silt (r = 0.19), organic carbon (r = 0.11) and soluble salts (r = 0.16) content of the soils. The above correlation shows that there exist a close relationship between the moisture retention by the soil and mechanical fraction as well as organic carbon content of the soils which is attributed to the well documented facts that the absorptive forces of the soils are associated with clay, silt and humus fraction of the soil (Gupta *et al*., 1983; Diwakar and Singh, 1992; Patgiri *et al*., 1993; Yadav *et al*., 1995; Bhaskar and Nagaraju, 1998; Sharma, 2000 and Challa *et al*., 2000).

5.2.6 Available Water Capacity (AWC):

The amount of available water content varied between 0.11 to 0.20 and 0.11 to 0.22 m^3 m^{-3}, respectively in slight to moderate and moderate to highly sodic soils. Further, the available water did not exhibit much variation in there content in both groups of soils (Table 4.1.26). The available water content seemed to have influenced by soil texture, as is evident from a positive correlation with clay (r = 0.45) and silt + clay (r = 0.47) and negative correlation with sand (r = -0.42). There exist a poor correlation between available water capacity and organic carbon content of the soil probably because of its low content and little variation (Table 4.1.27) along depth of the pedons (Srivastava *et al.,* 1998).

Plant available water capacity (PAWC) of the soils under study presented in table 4.1.26 indicated that the PAWC values ranged between 93.0 to 138.0 mm and 85.0 to 136.5 mm for slight to moderate and moderate to highly sodic soils, respectively, depending upon soil depth and available water retained. The distinctly lower value of PAWC in pedon P_{10} (85.0 mm) was due to the minimum depth of the pedon.

5.3 CHEMICAL CHARACTERISTICS

5.3.1 pH and Electrolyte Concentration (ECe):

It is clearly evidenced from the data presented in table 4.1.27 that all the soils under investigation were alkaline rather alkali in nature and the pH value so observed ranged between 7.94 to 10.05. The range of pH values showed an increase with an increase in the sodicity upto a certain level and the respective range recorded for slight to moderate and moderate to highly sodic soils were 7.94 to 9.57 and 8.06 to 10.05. Further, in general, the pH value of the study area increased with an increase in depth of pedons examined. Data on pH when compared with exchangeable sodium percentage (ESP) presented in table 4.1.31, it could be inferred that, in general, an increase in ESP resulted in corresponding increase in soil pH (r = 0.72). An increase in pH value with an increase in ESP of the salt-affected soil have also been reported by Dubey and Sharma (1988); Tiwari *et al.* (1983); Kumar and Kumar (1993); Verma (1995); Yeresheemi *et al.* (1997); Challa *et al.* (2000) and Garg *et al.* (2000).

The ECe value in present investigation ranged between 0.59 to 5.46 dS m^{-1} (Table 4.1.27). The data presented in the table 4.1.27 indicated that, in general, the soils under study followed a bimodal trend alongwith depth. This may be ascribed to dispersion of sodic soils in surface soil layers (soil above 30cm) and presence of horizon of secondary accumulation of calcium carbonate at lower depth. It could be ascribed to the cementing nature of dispersed layer and secondary lime which restricted the movement of soil water beyond this point, resulting in the maximum accumulation of salts in soil under examination (Naidu *et al.,* 1993; Yeresheemi *et al.,* 1997 and Pal *et al.,* 1999). The minimum amount at the surface and its gradual increase down the depth to a point of maxima in some pedons under study might be as a result of differential leaching of salts and its subsequent accumulation (Verma, 1995).

5.3.2 Organic Carbon:

The organic carbon content recorded was higher in surface horizons of the pedons under study in slight to moderate and moderate to highly sodic soils with respective range of 0.42 to 7.60 and 0.42 to 7.89 g kg^{-1}. Further, in general, the organic carbon content decreases gradually with an increase in the depth of the pedons under study. In general, a low organic carbon content was recorded in the study area which could be ascribed to the poor vegetation and rapid decomposition and mineralization of organic matter under prevailing conditions of high temperature and low rainfall (Mathur *et al.,* 1968 and Mehta *et al.,* 1969). Low amount of organic carbon and their progressive decrease alongwith depth was also reported by Tiwari *et al.* (1983), Kumar and Kumar (1993), Sahu and Dash (1993), Yeresheemi *et al.* (1997), Challa *et al.* (2000), Nayak *et al.* (2000), Garg *et al.* (2000) and Sharma *et al.* (2004) in salt-affected soils.

5.3.3 Calcium Carbonate:

The results of calcium carbonate content of the soil (Table 4.1.27) indicated that, in general, soils under study of both the groups are calcareous in nature (> 2% $CaCO_3$). The calcareousness in most of the pedons increased with an increase in depth of pedons which explains downward movement of calcium carbonate (Joshi and Kadrekar, 1987; Pal *et al.*, 1999 and Challa *et al.,* 2000). An increase in calcium carbonate with depth of the pedon in salt-affected soils have also been reported by a number of workers, Sharma *et al.* (1968), Darra *et al.* (1970), Bhargava *et al.* (1981), Tiwari *et al.* (1983), Joshi and Kadrekar (1987), Kumar and Kumar (1993), Mondal and Sharma (1997), Nayak *et al*. (2000) and Sharma *et al.* (2004).

5.3.4 Water Soluble Cations:

The distribution of water soluble cations are presented in table 4.1.28, wherein the water soluble sodium content was appeared to be a dominant cation, ranging between 3.3 to 29.4 me l^{-1}. Water soluble calcium and magnesium content represented a comparable figure in both groups of salt-affected soils examined with a respective range of 1.2 to 14.1 and 1.0 to 8.2 me l^{-1}. Water soluble potassium is the least fraction of soluble cation ranging between 0.2 to 2.9 me l^{-1}. The soluble calcium and magnesium content, in general, registered a high value in subsoil layers (calcareous horizon) of the pedons under study. A similar findings have also been reported by Sehgal and Stoops (1972) and Singh and Singh (1972). Further, the sodium content, in general, recorded a higher value in the subsurface horizons. A decrease in calcium concentration with depth as soil water gets reduced due to precipitation of calcium as $CaCO_3$ has also been reported by Challa *et al.* (2000). The dominance of water soluble sodium followed by calcium and magnesium in salt-affected soils have also been reported by Mehta *et al.* (1969), Darra *et al.* (1970), Sharma and Bhargava (1993), Yeresheemi *et al.* (1997), Challa *et al.* (2000), Nayak *et al.* (2000) and Sharma *et al.* (2004).

5.3.5 Water Soluble Anions:

The distribution of anions in salt-affected soils of district Chittorgarh are presented in table 4.1.29. Among the anions, chloride dominates in both group of soils (slight to moderate and moderate to highly sodic soils) followed by bicarbonate and sulphate. The carbonate content in present investigation was almost negligible in soils of all the pedons examined. Further, it was also evident that, in general, the majority of the pedons under examination showed a higher values of anions in subsurface horizons as compared to surface horizons (Balpande *et al.*, 1996). A higher value of chloride as compared to other anions in salt-affected soils have also been reported by Sharma *et al.* (1968), Darra *et al.* (1970), Sharma and Bhargava (1993), Mondal and Sharma (1997), Yeresheemi *et al.* (1997), Challa *et al.* (2000), Nayak *et al.* (2000) and Sharma *et al.* (2004).

5.3.6 Cation Exchange Capacity (CEC):

The cation exchange capacity (Table 4.1.30) exhibited a narrow variation in slight to moderate sodic soils and the range recorded was 15.89 to 26.92 cmol (p+) kg^{-1}. However, a wider range in CEC was observed in moderate to highly sodic soils and the range recorded was between 12.49 to 38.97 cmol (p+) kg^{-1}. The CEC of soils, in general, showed an increasing trend with an increase in the depth of pedons under study. The CEC observed in these soils is essentially contributed by their clay content, as the soils of the region are low in organic carbon (Table 4.1.27) content contributing least towards this parameter (Yeresheemi *et al.*, 1997). A highly positive correlation exist between CEC and clay content ($r = 0.851$), while a poor correlation exhibited between CEC and organic carbon content ($r = 0.164$) of the soil in the present investigation. Lavati *et al.* (1969) and Sangwan (1978) are also in close confirmation with the present investigation. The clay fraction of the soil being the main contributor of CEC in salt-affected soils have also been reported by Dubey and Sharma (1988), Kumar and Kumar (1993), Sahu and Dash (1993), Raj Kumar *et al.* (1995), Mondal and Sharma (1997), Yeresheemi *et al.* (1997), Challa *et al.* (2000) and Sharma *et al.* (2004).

5.3.7 Exchangeable Cations:

It is obvious from the data pertaining to exchangeable cations presented in table 4.1.30, that calcium is the dominant cation on the exchange complex in slight to moderate sodic soil examined and the order of exchangeable cations observed was $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. However, moderate to highly sodic soils showed preponderance of sodium exchangeable cations on the exchange complex and the order observed was $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$, indicating that a considerable amounts of sodium has gained entry into the soil exchange complexes of these areas (Vinayak *et al.,* 1981). From the examination of data it was further evident that, in general, the exchangeable cations (Ca^{2+}, Mg^{2+} and Na^{+}) recorded a higher values in subsurface layers of various pedons under investigation, while, for the exchangeable potassium no specific trend of distribution was recorded down the depth of pedons. In general, the exchangeable Ca^{2+} and Mg^{2+} were dominant cations followed by Na^{+} and K^{+} ions on the surface soils of almost all the pedons. The exchangeable Na^{+} was higher than exchangeable Ca^{2+} and Mg^{2+} at lower depths in almost all the pedons. A highly positive correlation between exchangeable Na^{+} and ESP (r = 0.70 and 0.94 for slight to moderate and moderate to highly sodic soil, respectively) was observed in the present investigation. It was also observed that as the clay content (Table 4.1.25) increased, there was a corresponding increase in content of exchangeable cations. It can be inferred that increase in clay content provide more exchange sites to get the cations adsorbed on it (Gawande *et al.*, 1967 and Datta *et al.*, 1990). Pathak and Patel (1980), Bhargava *et al.* (1981), Tiwari *et al.* (1983), Qureshi *et al.* (1996) and Garg *et al.* (2000) also reported preponderance of exchangeable sodium in the salt-affected soils.

5.3.8 Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR):

In the present investigation about 30 per cent of soil could be categorized in slight to moderate sodic group, while rest of the soils (70%) could be placed in moderate to highly sodic group (Abrol *et al.*, 1988) based on the weighted mean of ESP values observed for the soils of the pedons examined. It could be inferred from the examination of data (Table 4.1.31) that the ESP values increased alongwith the depth of pedons. The SAR values observed for the soils of various pedons examined ranged between 2.70 to 16.62. However, in general, an increase in the values of ESP and SAR were exhibited with an increase in the depth of pedons examined under investigation.

There exist a highly positive correlation between pH and ESP (r = 0.72) and pH and SAR (r = 0.55) of the soil. An overall examination of the relationship between ESP and SAR values of the soils under study exhibited with a ‘r’ value 0.39. A statistically positive relationship between ESP and SAR have also been reported by Abrol *et al.* (1988), Gupta and Abrol (1990), Balpande *et al.* (1996), Ray *et al.* (1997) and Sharma (2000). However, the SAR values of the soils computed in present investigation were of lower magnitude (3.02 to 11.00 as weighted mean) as compared to the ESP values (16.60 to 42.21 as weighed mean) indicating a poor establishment of equilibrium between water soluble and exchangeable cations in the soils under field condition. A poor equilibrium status between ESP and SAR have also been reported by Sharma *et al.* (1968), Darra *et al.* (1970), Nayak *et al.* (2000) and Sharma (2000).

5.3.9 Gypsum Requirement:

The gypsum requirement of salt-affected soils of district Chittorgarh presented in table 4.1.31 indicated a range between 0.54 to 15.68 t ha^{-1}. The gypsum requirement of soils, in general, showed an increasing trend alongwith depth of pedons under study. The ESP and gypsum requirement of these soils when examined statistically indicates a highly positive relationship with a ‘r’ value 0.89. Reclamation of sodic soils involves the replacement of exchangeable sodium with calcium released from soluble calcium salt like gypsum which reduces ESP and improves the soil physico-chemical properties (Gupta and Abichandani, 1970; Abrol and Bhumbla, 1973; Abrol *et al.*, 1988; Gupta and Abrol, 1990; Verma *et al.,* 1995 and Pagaria *et al.,* 2004).

5.4 NUTRIENT STATUS:

5.4.1 Macronutrient Status:

It is obvious from the data pertaining to available macronutrient presented in table 4.1.32 that available nitrogen status of the study area, in general, was rated in low category, while, available phosphorus status could be categorized in medium category. However, available potassium status was categorized as high (Darra *et al.,* 1970; Raj Kumar *et al.,* 1995; Verma, 1995; Yeresheemi *et al.,* 1997 and Sharma, 2000). Further, the available nitrogen status of soil decreased as one proceed down the depth of the pedons examined. A high value of nitrogen in the surface soils and decreased alongwith depth of pedons could be attributed to the corresponding decrease in organic carbon ($r = 0.88$). The observation recorded in present study are in agreement with the findings of Sharma *et al.* (1968), Darra *et al.* (1970), Kumar and Kumar (1993), Kumar *et al.* (1995), Yeresheemi *et al.* (1997) and Sharma (2000).

The available phosphorus status in slight to moderate and moderate to highly sodic soils was identical and decreased in calcareous zone down the depth of pedons. The decrease in available phosphorus status down the depth may be attributed to a higher calcium carbonate content in subsurface horizons of the pedons (Singh, 1999) resulting in fixation of phosphorus and thereby decreasing its availability. The available potassium status did not register a definite trend down the depth of the pedons examined. A higher content of potassium in the present investigation may be attributed to mineralogy of the soil, containing a greater proportion of feldspar group of minerals (Miller and Donahue, 1982; Pal, 1985 and Yeresheemi *et al.,* 1997).

5.4.2 Micronutrient Status:

The available micronutrient cation values of salt-affected soils under study ranged between 0.19 to 1.46, 0.98 to 4.37, 2.76 to 10.53 and 0.21 to 1.46 mg kg^{-1} for Zn, Fe, Mn and Cu, respectively. All the micronutrient cations showed a wide variation and a gradual decrease in its content as one traverse down the depth of various pedons. On the basis of weighted mean the salt-affected soils under study could be categorized as deficient for Zn and Fe, while, sufficient for Mn and Cu.

In alkaline range (pH > 8.0) zinc forms negatively charged ions called zincate (ZnO_2). Although the solubility of zincate ions increases with rise in pH but the interaction with calcium results in the minimum zinc solubility product and thereby zinc deficiency. The problem of zinc deficiency is more aggravated in calcareous soil (Table 4.1.27) wherein $CaCO_3$ acts as a strong absorbent of Zn. Next to zinc, iron is often the limiting micronutrient in alkali soils due to high pH and presence of calcium carbonate (Somani and Totawat, 1993).

There exist a highly positive correlation between the Zn availability and organic carbon content of the soil (r = 0.61) which is attributed to Zn mobilization by dispersed organic matter in the sodic soil (Jaffery and Uren, 1983), while a similar trend for Cu (r = 0.78) could be because of formation of natural stable complexes in soil solution (Arora and Sekhon, 1981 and Swarup and Yaduvanshi, 2000). Lack of close association of available Fe and Mn with organic carbon (r = 0.29 and 0.12, respectively) indicates inorganic phase as their major source in the soil (Arora and Sekhon, 1981). A significant positive correlation between organic carbon and micronutrient cation availability has also been reported by Yeresheemi *et al*. (1997).

Among the other soil properties, the correlation studies showed that there exist a negative correlation between pH, $CaCO_3$ and ESP with micronutrient cations under study. The negative correlation observed between pH and DTPA extractable metallic cation were to the tune of -0.71, -0.63, -0.55 and -0.52 for Zn, Fe, Mn and Cu, respectively. Agarwal *et al.* (1964) and Bhumbla and Dhingra (1964) and observed negative relationship between pH and the micronutrient cations. Kumar *et al.* (1995) and Yeresheemi *et al*. (1997) have also reported similar results while working on salt-affected soils.

5.5 GROUND TRUTH

Effective and accurate identification of area adjoining to salt-affected soils ground truth were collected from surface layers (0-15 cm) from other fields of the study area. The results of ground truth indicated that according to salinity appraisal 93 per cent of ground truth (Table 4.3.2) comes under non-saline soils (ECe 0-2 dS m^{-1}), while, on the basis of sodicity appraisal 87 per cent ground truth (Table 4.3.3) comes under none to slight sodic (ESP < 15) group. These ground truth did not exhibit any correlation with the soils of pedons under study which may be attributed to the addition of tank bed soil on the surface transported from nearby tank, a common practice of the area under study. The practice of addition of tank bed soil is repeated after every three to four years depending upon the availability. It also corroborate with the fact that alkali soils are present in small irregular areas in semi-arid and arid region, which is known as “slick spots” (Richards, 1954). However, 13 per cent ground truth comes under the category of slight to moderate sodic (12 %) and moderate to highly sodic (1 %) which require special attention for their reclamation and further management, else otherwise, with progressive sodification/alkalization these soils will become more problematic.

5.6 CATEGORIZATION OF WELL WATER:

In categorization of irrigation water, it is presumed that the water will be used under specific conditions with respect to several factors influencing its quality in relation to its use. The salts dissolved in irrigation water will accumulate in the soil in amounts which may affect plant growth depends on one or more of the several parameters *viz.*, soil properties, plant characteristics, climate particularly the rainfall and temperature, irrigation and management practices. Here, guidelines for interpretation of water quality for irrigation as suggested by Ayers and Westcot (1976) have been used to categorize irrigation water.

5.6.1 Salinity:

The electrical conductivity of the well waters indicated that majority of samples from the study area could be categorized in low salinity water with a narrow range of EC value ranging between 1.62 to 1.88 dS m^{-1} as weighted mean. Based on the guidelines suggested by Ayers and Westcot (1976) it can be inferred that out of forty six representative well water samples collected from the study area five (10.87%) samples fall in no problem category, thirty four (73.91%) samples qualify for increasing problem category and rest seven (15.21%) samples come under the severe problem category on account of salinity hazard when used for irrigation on long term basis.

5.6.2 Permeability:

The adj. SAR value for the irrigation water samples collected from the study area ranged between 4.16 to 39.51 and based on the guidelines computed for mixed mineralogy, six (13.04%) samples fall in no problem class, nineteen (41.30%) samples come under increasing problem class and rest twenty one (45.66%) samples qualify for severe problem class. Out of 46 water samples hardly six samples are having adj. SAR below 9 indicating their continuous use might have lead the development of sodicity in the area.

5.6.3 Specific Ion Toxicity:

The chemical composition of well waters sampled from the study area when computed for adj. SAR parameter the values ranged between 4.16 to 39.51. Out of 46, 42 (91.31%) samples were having adj. SAR value > 9 and could be rated in the severe problem category. However, from the view point of chloride toxicity abut 46 per cent of water samples (21 samples) could be categorized under no problem class (chloride < 4 me l^{-1}), while 26 per cent (12 samples) samples comes under the category of increasing problem (chloride 4-10 me l^{-1})

and rest of the 28 per cent (13 samples) water samples are grouped under severe problem of chloride toxicity (chloride > 10 me l^{-1}). Out of 46 water samples hardly 6 samples (13%) are having boron level below 0.75 mg l^{-1} which could be categorized under no problem class, while, 33 samples (72%) falls into the category of increasing problem (boron 0.75-2.0 mg l^{-1}) and rest of the 7 samples (15%) are grouped under severe problem of boron toxicity (boron > 2.0 me l^{-1}).

5.6.4 Miscellaneous Factors:

The chemical analysis of water samples collected from the district Chittorgarh from the area engraved with both slight to moderate and moderate to highly sodic soils indicated that the NO_3^--N level in all the 46 water samples collected could be categorized in increasing problem category (NO_3^--N 5-30 mg l^{-1}). However, from the view point of HCO_3^- content 87 per cent (40 samples) of the water samples fall into the category of increasing problem (HCO_3^- 1.5-8.5 me l^{-1}) and rest of 13 per cent (6 samples) of the water samples come under the severe problem category (HCO_3^- > 8.5 me l^{-1}) as described by Ayers and Westcot (1976).

Further, the pH of different water samples collected lies in the range of 7.37 to 8.67, which are almost nearer to normal range. From the data presented in table 4.3.1 it is also evident that fluoride content in the well waters of the study area ranged between 0.56 to 5.72 ppm. Only 8 samples falls under the no problem category, while, rest of the 38 samples having high fluoride content (F > 1 mg l^{-1}) and will create a problem when used continuously on all types of soils (National Academy of Sciences and National Academy of Engineering. 1972). The fluoride level is more than one third of the water samples is above 2 ppm and that is questionable not only from the view of drinking purpose for human being but also for livestock.

Impact of irrigation water:

All the water samples under study may cause environmental and degradational problems in soils irrigated with them. The changes brought in due to irrigating a soil may be beneficial or detrimental, depending upon the composition and concentration of the dissolved salts in water and original characteristics of the soil (Rengasamy and Olsson, 1995).

In the present study the water collected from the proximity of slight to moderate and moderate to highly sodic soils were low in salinity. Most of the water of the study are based on adj. SAR and bicarbonate hazards, fall in moderate and/or severe problem category and thus their continuous use may lead to the development of permeability problem and/or development of sodicity in the area (Ayers and Westcot, 1976 and Myers *et al.*, 1990). The development of sodic soils in the study area may thus be attributed to poor quality of irrigation water being continuously used for irrigation. On account of sodium and chloride toxicity the water samples under study, in general, were rated as moderate to severe and thus may be the cause of poor yield of the crops being grown in the area (Abrol *et al.*, 1988).

Further the fluoride content in well waters is high which may be hazardous as it might be transmitted to the food chain through the crops being grown in the area. Most of the fluoride ion from the irrigation water is retained in the surface and is not being leached down even after a considerable period (Specht and MacIntire, 1961). These waters are unsuitable for drinking and may prove deleterious to the quality of fodder and consequently injurious to cattle (Kanwar and Mehta, 1968; Abrol *et al.*, 1988 and Gupta *et al.*, 1995).

A specific ion toxicity problem is different from the salinity, the sodicity and the permeability problems, since the toxicity occurs within the crop itself as a result of the uptake and accumulation of certain constituents from the irrigation water and may occur even though salinity is low. In present study all the water samples, in general, were rated as moderate to severe for boron, NO_3^--N and bicarbonate ion content and may be the cause of low crop yield being grown in the area. Toxicity problem often accompanies and is a complicating part of a salinity or permeability problem (Ayers and Westcot, 1976 and Somani and Totawat, 1993).

5.7 ALTERNATE AND SUSTAINABLE LAND USE PLANNING:

Slight to moderate sodic soils of the district Chittorgarh are moderately suitable for wheat, sorghum and pearl-millet. Bounty of these crops can be harvested with slight fertility manipulation and corrective measures for sodicity problem. However, for cotton, soybean, barley and mustard these sols were found marginally suitable. With the support of proper irrigation, fertility manipulation and amelioration of sodicity problem, this class of soil could be updated from marginally to moderate suitability class for these crops. Further, these soils found non-suitable for maize crop, however, with intensive corrective measures these soils could be amended to marginally suitable for maize.

The soils of moderate to highly sodic group were marginally suitable for wheat, pearl-millet, sorghum and barley. With the adoption of corrective measures, such as addition of organic manures, alongwith an ameliorant for sodicity problem and providing irrigation facilities, these soils can be moderately cultivated for the crops in question. On account of major limitations posed by sodicity and fertility these soils were found non-suitable for cotton, mustard, maize and soybean, even with best corrective measures these crops could be cultivated marginally.

Reclamation of alkali soils for arable farming is a feasible, economically viable and lucrative proposition. Despite of considerable potential to increase production and income, there are some socio-economic constraints which hinder the alkali soil reclamation on a large scale. Therefore, we have to deviate from crop production to horticultural plants (trees), agroforestry and pasture and/or combination of these in situation where reclamation of entire land is not remunerative or economical. There are some grass species which are most suitable for alkali land i.e. Karnal grass (*Diplachne fusca*), blue panic (*Panicum antidotale*) and paragrass (*Brachiaria mutica*) etc. These grasses can successfully grown on Panchayat lands and used for pasture on large scale utilization of alkali lands (Gupta *et al.,* 1995).

Forestry in such lands offers a good alternative land use for extending the forest areas which is far below the minimum requirement of one third of total land surface. Afforestation in these barren lands would also contribute to the maintenance of healthy agro-ecological system and averting the environmental hazards. Village community lands and alkali lands with undulating topography offer enormous scope for afforestation. Certain forest species have been identified which have higher tolerance to the alkali conditions (Appendix III) can be suggested for plantation in these areas. Certain fruit trees i.e. sapota, pomegranate, *aonla, ber,* lime, date palm etc. can also be grown successfully with amelioration of localized pit/hole and adoption of certain plantation techniques.

Pit technique: Depending upon type of soil and depth of kankar layer, pit of different sizes are used for planting trees, in general, 1 m X 1 m X 1m pit size is good enough which will also take care of the kankar/hard layer, if any. After digging pit is refilled with the amended soil or good soil with addition of required quantity of gypsum and FYM (Gupta *et al.,* 1995).

Auger hole technique: This technique of tree plantation in alkali soils involves digging of auger holes of 120 cm to 180 cm depth and 15 cm diameter using tractor mount auger. Auger holes are filled by mixing the alkali soil from the planting site, 2-3 kg gypsum and 8-10 kg FYM per hole before planting of the saplings. Due care should be taken to avoid air-voids through intermittent watering while filling these auger holes. This technique involves reclamation of a very small percentage of the total area and thus is an economically feasible and viable technique. In these holes the roots are trained to grow deeper into the soil where relatively better environment is present (Gupta *et al.,* 1995).

5.8 RECLAMATION AND MANAGEMENT STRATEGIES:

In general, reclamation of sodic soils involves the replacement of exchangeable sodium with calcium (Abrol *et al.,* 1988 and Gupta and Abrol, 1990). In present investigation, the salt-affected soils of district Chittorgarh require chemical amendments for their amelioration and management practices such as adoption of green manuring (Dhaincha) or addition of organic manures to build up the fertility and boost up crop production.

The use of gypsum or posphogypsum @ 25 % G.R. in integration with either pressmud @ 15 t ha^{-1} or spentwash 7.5 lac L ha^{-1} followed by a green manuring with dhaincha to speed up the reclamation process. This set of treatment is having a beneficial effect in reducing soil pH and ESP and provides a congenial soil environment in the rhizosphere of the crop (Pagaria *et al.,* 2004) leading to enhanced crop production.

Further, agronomic practices such as soil profile modification (chiseling, deep ploughing), irrigation management for leaching after reclamation with chemical amendment and adoption of salt/alkali-tolerant cultivars could help in boosting up of the crop production in the area (Abrol *et al.,* 1988; Gupta and Abrol, 1990; Somani and Totawat, 1993 and Gupta *et al.,* 1995).

5.9 SUSTAINABILITY ASSESSMENT:

After comparing different indicators of sustainability with criteria and scoring proposed by Lal (1994), it was inferred that cumulative rating index (Table 5.9.1) scores were 32 and 33 for slight to moderate sodic soils (S_2) and moderate to highly sodic soils (S_3), respectively. Thus, these soils are sustainable with alternate land use. The overall sustainability of these soils fall in order of $S_2 < S_3$ with respect to severity of sodicity.

Table 5.9.1 Sustainability : Summation of weighting factors for relevant properties of salt-affected soils of district Chittorgarh

Properties	**Slight to moderate sodic soils (S_2)**	**Moderate to highly sodic soils (S_3)**
Effective rooting depth	3	3
Bulk density	5	5
Texture	3	3
Structure	3	3
Consistency	3	3
AWC	3	3
pH	4	4
ECe	1	1
ESP	2	3
Organic carbon	5	5
Total	32	33

6. SUMMARY AND CONCLUSION

An integrated approach of image interpretation coupled with field studies was followed to delineate the salt-affected soils of district Chittorgarh. After delineating the sites, twenty representative pedons were exposed and studied with the sole objectives of furnishing the much needed basic soil information for their characterization, classification, amelioration and adoption of suitable management practices. Simultaneously, ground truth and underground water samples from existing wells in the vicinity of the pedon under study area were also collected for laboratory analysis and characterization. Physiographically the study area is a fairly plain with scattered hills and in general, moderately to well-drained. The climate is semi-arid type with high temperature in summer, bracing winter and medium rainfall which is essentially monsoonic in nature.

For the ease of comparison of results as well as to analyze constraints and sustainable management, weighted mean of ESP of each pedon was computed and the pedons were grouped into two categories *viz*. slight to moderate sodic soils (ESP 15-30) and moderate to highly sodic soils (ESP 30-50).

Morphological features have revealed that soils of different groups showed a wide variation. Soils of the study area exhibited very dark grayish brown (10 YR 3/2 M) to light brownish gray (10 YR 6/2 M) colour. The texture varied from sandy clay loam to clay loam, while, structure in the study area was sub-angular blocky with weak to moderate strength which remained almost uniform. However, a massive soil structure in lower depth of the majority of pedons was also observed. Further, the soils under study produced effervescence with dilute hydrochloric acid and in general, become violent as one move down the depth of pedons.

The bulk density of soils increased, while, porosity decreased down the depth of pedons. However, particle density showed an almost identical value in different groups of salt-affected soils examined. Component of mechanical composition specially sand and silt were irregularly distributed in different pedons indicating parent material discontinuity in their depositional cycle, while, the clay fraction, in general, was more concentrated in subsurface layers of various pedons evidencing the process of illuviation verifying the soils to be alluvium in origin. It was also noticed that, in general, in majority of the pedons the magnitude of water retention observed were higher for subsurface layers as compared to surface layers of pedons at both -0.033 MPa and -1.5 MPa tension. Like that of moisture retention, AWC values computed were also recorded somewhat of higher magnitude in subsurface layers as compared to surface layers. The plant available water capacity (PAWC) of pedons were recorded higher for slight to moderate sodic soils as compared to moderate to highly sodic soils, which was computed from the soil depth and available water retained there in.

The soils of the study area were alkali in nature with a pH values ranging between 7.94 to 10.05, which recorded an increase alongwith depth of the pedons. The ECe values ranged between 0.59 to 5.46 dS m^{-1} and followed a bimodel trend alongwith depth of the pedons under investigation. In general, low organic carbon content was recorded in the study area (< 5 g kg^{-1} as weighted mean) which decreases gradually with an increase in the depth of the pedons. The calcareousness in most of the pedons increased with an increase in the depth and majority of the pedons in the area possesses calcic horizon in substratum.

The soluble cations and anions in the saturation extract showed a preponderance of sodium among cations and chloride among anions, while the content of calcium and magnesium were almost comparable, whereas, potassium was of lower magnitude. Further, bicarbonate content dominated over sulphate, while, carbonate content was almost negligible among the anions.

The cation exchange capacity values, in general, showed an increasing trend with an increase in the depth of pedons and is essentially contributed by their clay content since the organic carbon content of the region was invariably low. Among the exchangeable cations calcium dominated the exchange complex followed by sodium which dominated over magnesium in slight to moderate sodic soils, while, sodium was dominating cation followed by calcium and magnesium in moderate to highly sodic soils. The exchangeable potassium was present in small amounts in both the groups of soils. The ESP and SAR values in the study area increases alongwith the depth of pedons. Though, the ESP and SAR values exhibited a positive relationship but magnitude of values computed for SAR was distinctly low as compared to ESP. The gypsum requirement of soils, in general, showed an increasing trend alongwith depth of pedons and exhibited a highly positive correlation with ESP.

The available nitrogen, phosphorus and potassium status of the soils of pedons under investigation were low, medium and high, respectively. The DTPA extractable micronutrient cations showed a wide variation and a gradual decrease in its content alongwith depth of pedons. On the basis of weighted mean the soils under study, in general, could be categorized as deficient for Zn and Fe, while, sufficient for Mn and Cu.

The quality of irrigation waters in the present investigation was rated as low to medium salinity water, although 74 per cent samples were categorized as increasing problem on account of salinity hazard when used for continuous irrigation. Based on adj. SAR and specific ion toxicity (sodium, bicarbonate and chloride), the water samples were rated as moderate and/or severe problem category, thus their continuous use may lead to the development of toxicity in crop being grown. On account of boron toxicity 87 per cent of water samples were categorized as moderate to severe, while, for NO_3^--N toxicity these water samples were rated under moderate category. The fluoride level in more than 40 per cent of the water samples was above 2 mg l^{-1} having no toxicity problem on their continuous use, but their use for drinking purpose is questionable not only for human being but also for livestock.

The slight to moderate sodic soils of the study area were found moderately suitable for sorghum, pearl-millet and wheat, while, marginally suitable for soybean, cotton, barley and mustard. These soils were found non-suitable for maize. On the other hand, moderate to highly sodic soils were marginally suitable for sorghum, wheat and barley, while, non-suitable for soybean, maize, cotton and mustard. For slight to moderate sodic soils reclamation and management alternatives have been suggested. While, for moderate to highly sodic soils the reclamation is not an economically viable proposition and thus their alternative uses have been suggested which includes cultivation of alkali tolerant grasses (Karnal grass, para grass and bermuda grass etc.) on village community land, converting them into pasture. Another best alternative is horti-pasture by growing tolerant fruit trees using pit or auger hole technique, which involve reclamation of a very small percentage of the total area, is not only economically viable but also remunerative.

In the study area 23,615 ha of land was engraved with sodicity problem, of which, 6,954 ha was categorized as slight to moderate, while, 16,661 ha as moderate to highly sodic soils. The soils of study area were taxonomically classified in order Inceptisol and Entisol.

It can be concluded from the results of the present investigation that the visual interpretation of satellite imageries coupled with field studies was found effective in the identification and delineation of salt-affected soils in district Chittorgarh. The soils under study were calcareous sodic in nature, which also increases with depth. These soils have developed from calcareous parent material accompanied with poor quality of irrigation water having high adj. SAR values. The soils under study were categorized under slight to moderate and moderate to highly sodic soils and were alluvium in origin belonging to order Entisol and Inceptisol. These soils were mainly confined in Kapasin, Dungla and Rashmi tehsil, while, distributed in patches in Begun and Pratapgarh tehsil of Chittorgarh district, which required appropriate management alternatives. The slight to moderate sodic soils must be reclaimed using chemical and organic amendment in integration, while, moderate to highly sodic soils can be managed by growing alkali tolerant fruit trees with localized reclamation employing pit or auger hole technique, except village community land which should be converted into pasture by growing alkali tolerant grasses.

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Characterization of salt-affected soils and water resources in sub-humid Southern plains of Rajasthan

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ABSTRACT

An investigation was carried out by adopting an image interpretation coupled with field studies to characterize the salt-affected soils of Chittorgarh district. In order to establish the cause-effects relationship, methodically selected 20 pedons were studied morphometrically in the field, and soil samples were drawn for the determination of physical and chemical characteristics in the laboratory. Similarly, 71 ground truth were also collected from the other fields of the study area to establish correlation with pedons, if any. Simultaneously, 46 ground water samples were also collected from existing well/tube well in the study area for their quality appraisal. For the ease of comparing results, the soils were grouped in two categories slight to moderate and moderate to highly sodic soil based on the ESP values. Soils under study were shallow to deep, calcareous, sandy clay loam to clay loam and very dark grayish brown to light brownish gray in colour. These soils were alluvium in origin and the components of mechanical fraction irregularly distributed in pedons indicating parent material discontinuity in depositional cycles. In soil water extract sodium dominated the cationic composition closely followed by the calcium and magnesium whereas among anions chloride dominated the composition. Further, the CEC values was higher in substratum and mainly contributed by clay, since the soils of the study area were low in organic carbon. In general, sodium was the dominant exchangeable cation followed by calcium and magnesium. The sodicity of soil increased with depth of pedons. The available nutrient status of soils indicated that they were low in N, medium in P and

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high in K, while, were deficient in Zn and Fe and sufficient for Mn and Cu. The irrigation water quality in the proximity of these soils were low to medium in salinity, but high in adj. SAR which led to development of permeability and sodicity problem in the area. Further, looking to the chloride and boron contents of the water analysed, they were prone to develop moderate to severe degree problem in soils irrigated with them. Ground truths so collected were not correlated with the characteristics of pedons under study. A total area of 23,615 ha is salt-affected comprising 6,954 and 16,661 ha of slight to moderate and moderate to highly sodic soils, respectively and need adoption of appropriate management techniques. The slight to moderate sodic soils must be ameliorated with suitable chemical amendment in integration with organic amendments to boost up their productivity, however, moderate to highly sodic soils should be used for growing alkali tolerant fruit trees by using localized reclamation employing pit or auger hole technique, which is not only economically viable but also remunerative alternative. The land resources pertaining to district Chittorgarh under study have been evaluated for suitability for eight crops keeping in view the existing soil site characteristics prevailing in the area and are classified as a member of Entisol and Inceptisol order.

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vf/kdrk oky ty dh flpkb u bu enkvk e e/;e l rh{.k leL;k dk ior fd;k gA tk Hkh ;FkkFk Hkfe ueu fy, x, mudk ^iMku* d x.kk l dkb lc/k ugh ik;k x;kA v/;;u {k= e dy 23]615 gDV;j yo.k&iHkkfor enk ikb xb ftle l 6]954 gDV;j vYi l e/;e rFkk 16]661 gDV;j e/;e l vfr{kkjh; enk dk {k= gA bu enkvk l vPNh Qlyk Riknu yu gr mfpr ic/ku rduhd viuku dh vko';drk gA

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APPENDIX-I

Climatic and soil site suitability criteria

Characteristics	Rating class*				
	S_1	S_2	S_3	N_1	N_2
1	**2**	**3**	**4**	**5**	**6**
		(a) Sorghum			
Climatic characteristics:					
Total rainfall (mm)	650-750	550-650	450-550	< 450	--
Rainfall growing season (mm)	500-700	400-500	300-400	< 300	--
Rainfall during critical period	--	--	--	--	--
Length growing period (days)	150-105	105-90	< 90	--	--
Mean temp. growing season (°C)	24-32	22-24	20-22	< 20	--
Mean max. temp. growing season (°C)	31-33	33-35	> 35	--	--
Mean min. temp. growing season (°C)	< 18	15-18	< 15	--	--
Mean R.H. in growing season	50-70	40-50	< 40	--	--
Length of dry spells (days) after sowing & during flowering	< 10	10-15	15-21	> 21	--
Site characteristics:					
Slope (%)	< 3	3-5	5-8	> 8	--
Erosion	e_1	e_2	e_3	--	--
Drainage	Well to mod. Well	Imp. & somewhat excessive	Poor & excessive	--	--
Water stagnation (days)	< 3	4	5	> 5	--
AWC (mm/m)	> 150	100-150	50-100	< 50	--
Stoniness % (surface)	< 15	15-40	40-60	> 60	--
Soil characteristics:					
Texture (clay %)	slc, sicl, cl, sc	sil, sci	sl, cm	s, ls	--
Coarse fragments (vol. %)					
Within 50 cm	< 15	15-35	35-50	> 50	--
Below 50 cm	5-40	40-75	> 75	--	--
Depth (cm)	> 75	50-75	< 50	--	--
$CaCO_3$ (%) (within 50 cm)	< 10	10-25	> 25	--	--
Soil fertility :					
CEC [cmol (p^+) kg^{-1}]	> 20	10-20	< 10	--	--
B.S. (%)	> 50	35-50	< 35	--	--
O.C. (%) (0-15 cm)	> 0.50	0.20-0.50	< 0.20	--	--
pH	6.5-5.5	5.5-5.0	< 5.0	--	--
	7.5-8.0	8.0-8.5	8.5-9.0	> 9.0	--
Salinity/Alkalinity (n):					
ECe (dS m^{-1})	< 4	4-8	8-10	> 10	--
ESP	< 10	10-15	> 15	--	--

(b) Soybean					
1	**2**	**3**	**4**	**5**	**6**
Climatic characteristics:					
Total rainfall (mm)	> 750	650-750	550-650	< 550	--
Rainfall growing season (mm)	> 600	500-600	400-500	< 400	--
Rainfall during critical period	--	--	--	--	--
Length growing period (days)	> 110	100-110	90-100	< 90	--
Mean temp. growing season (°C)	25-28	28-30	30-34	> 34	--
Mean max. temp. growing season (°C)	--	--	--	--	--
Mean min. temp. growing season (°C)	--	--	< 20	--	--
Mean R.H. in growing season	> 70	50-70	< 50	--	--
Length of dry spells (days)	Flowering to pod filling is critical				
	< 4	4-8	8-12	> 12	--
Site characteristics:					
Slope (%)	< 3	3-5	5-8	> 8	--
Erosion	--	--	--	--	--
Drainage	Well to mod. Well	Poor/ excessive	--	--	--
AWC (mm/m)	> 200	150-200	100-150	50-100	< 50
Stoniness % (surface)	5-10	10-15	15-25	> 25	--
Soil characteristics:					
Texture	cl, sicl, l, sil, scl	sl, c	cm, ls	s	--
Coarse fragments (vol. %)					
Within 50 cm	< 15	15-25	25-35	> 35	--
Depth (cm)	> 60	50-60	40-50	< 40	--
$CaCO_3$ (%)	< 10	10-20	> 20	--	--
Soil fertility :					
CEC [cmol (p^+) kg^{-1}]	> 20	20-10	< 10	--	--
B.S. (%)	> 50	50-35	< 35	--	--
O.C. (%) (0-15 cm)	> 0.5	0.5-0.2	< 0.2	--	--
pH	6.5-7.5	7.5-8.5	> 8.5	--	--
Salinity/Alkalinity (n):					
ECe (dS m^{-1})	< 2	2-3	3-4	> 4	--
ESP	< 5	5-10	10-15	> 15	--

© Cotton					
1	**2**	**3**	**4**	**5**	**6**
Climatic characteristics:					
Total rainfall (mm)	700-1050	550-700	< 550	--	--
Rainfall growing season (mm)	600-950	450-600	< 450	--	--
Rainfall during critical period (soil development)	100-120	--	--	--	--
Length growing period (days)	> 135	120-135	< 120	-	--
Mean temp. growing season (°C)	22-32	> 32	--	--	--
Mean max. temp. growing season (°C)	--	--	> 36	--	--
Mean min. temp. growing season (°C)	--	--	< 19	--	--
Mean R.H. in growing season	60-90	--	< 50	--	--
Length of dry spells (weeks)					
July (beginning)	< 1	-	> 1	--	--
August (end)	< 2	--	> 2	--	--
Site characteristics:					
Slope (%)	< 3	3-5	> 5	--	--
Erosion	e_1	e_2	e_3	--	--
Drainage	Well to moderate well	Imper-fect	Poor & excessive	--	--
Water stagnation (days)	< 2	2-3	3-5	> 5	--
AWC (mm/m)	> 150	100-150	50-100	--	--
Stoniness % (surface)	< 15	15-40	> 40	--	--
Soil characteristics:					
Texture	sic, sicl, c, cl	sci, sil, l, sc	si	s, ls	--
Coarse fragments (vol. %)					
Within 50 cm	< 15	15-35	> 35	--	--
Below 50 cm	5-35	35-50	> 50	--	--
Depth (cm)	> 75	50-75	25-50	< 25	--
$CaCO_3$ (%)	< 10	10-20	> 20	--	--
Soil fertility:					
CEC [cmol (p^+) kg^{-1}]	> 20	< 20	--	--	--
B.S. (%)	> 50	35-50	< 35	--	--
O.C. (%) (0-15 cm)	> 0.75	0.5-0.75	< 0.50	--	--
pH	8.0-8.5	8.5-9.0	--	> 9.0	--
Salinity/Alkalinity (n):					
ECe (dS m^{-1})	< 2	2-4	> 4	--	--
ESP	< 10	10-15	> 15	--	--

(d) Maize					
1	**2**	**3**	**4**	**5**	**6**
Climatic (c):					
Precipitation growing cycle (mm)					
First month	500-750	400-500	300-400	--	< 300
Second month	100-175	75-100	60-75	--	< 60
Third month	150-200	120-150	70-120	--	< 70
Fourth month	100-165	80-100	60-80	--	< 60
Mean temp. growing cycle (°C)	24-32	32-35	35-40	--	> 40
Mean max. temp. growing cycle (°C)	17-24	24-28	28-30	--	> 30
Topography (t):					
Slope (%)	0-2	2-4	4-6	--	> 6
Wetness (w):					
Drainage	Good to moderate	Imper-fect	Poor	Poor but drainable	Poor not drainable
Physical characteristic (s):					
Texture/Structure	c	cl, scl	fs, s, < cs	--	cm, sicm
Coarse fragments (%)	0-15	15-35	35-55	--	> 55
Soil depth (cm)	> 75	75-50	50-20	--	> 20
$CaCO_3$ (%)	0-15	15-25	25-35	--	> 35
Gypsum (%)	0-4	4-10	10-20	--	> 20
Soil fertility characteristics (f):					
CEC [cmol (p^+) kg^{-1}]	> 16	< 16(-)	< 16(+)	--	--
B.S. (%)	> 50	50-35	35-20	< 20	--
O. C. (%)	> 0.6	0.4-0.6	< 0.4	--	--
pH	6.6-7.8	7.8-8.2	8.2-8.5	> 8.5	--
Salinity/alkalinity (n):					
ECe (dS m^{-1})	0-4	4-6	6-8	8-12	> 12
ESP	0-15	15-20	20-25	--	> 25

(e) Wheat					
1	**2**	**3**	**4**	**5**	**6**
Climatic (c):					
Precipitation (mm)	350-700	250-350	200-250	--	< 200
Monthly rainfall veg. stage	20-65	12-20	8-12	--	< 8
Monthly rainfall flowering stage	30-75	15-30	10-15	--	< 10
Monthly rainfall ripening stage	30-60	10-30	< 10	--	--
Mean temperature (°C)					
Vegetative stage	10-6	6-4	4-2	--	< 2
Flowering stage	18-12	12-10	10-8	--	< 8
Ripening stage	20-14	14-12	12-10	--	< 10
Topography (t):					
Slope (%)	0-2	2-4	4-6	--	> 6
Wetness (w):					
Drainage	Good to moderate	Imper-fect	Poor & aeric	Poor but drainable	Poor, but not drainable
Physical characteristic (s):					
Texture/Structure	c, l	scl	sl, lfs	--	cm, sicm
Coarse fragments (%)	0-15	15-35	35-55	--	> 55
Soil depth (cm)	> 50	50-20	20-10	--	< 10
$CaCO_3$ (%)	3-30	30-40	40-60	--	> 60
Gypsum (%)	0-5	5-10	10-20	--	> 20
Soil fertility characteristics (f):					
CEC [cmol (p^+) kg^{-1}]	> 16	< 16(-)	< 16(+)	--	--
B.S. (%)	> 50	50-35	< 35	--	--
O. C. (%)	> 0.4	< 0.4	--	--	--
pH	7.0-8.2	8.2-8.5	> 8.5	--	--
Salinity/alkalinity (n):					
ECe (dS m^{-1})	0-3	3-5	5-6	6-10	> 10
ESP	0-20	20-35	30-45	--	> 45

(f) Barley					
1	**2**	**3**	**4**	**5**	**6**
Climatic ©:					
Precipitation (mm)	200-400	200-300	150-200	--	< 150
Mean temp. vegetative stage (°C)	10-18	18-24	24-28	--	> 28
Mean temp. ripening stage (°C)	20-30	30-36	36-42	--	> 42
Topography (t):					
Slope (%)	0-2	2-4	4-6	--	> 6
Wetness (w):					
Drainage	Good to moderate	Imperfect	Poor	Poor	Poor
Physical characteristic (s):					
Texture/Structure	c, sil, l	scl	ls	-	cm, sicm
Coarse fragments (%)	0-15	15-35	35-55	--	> 55
Soil depth (cm)	> 50	50-20	20-10	--	< 10
$CaCO_3$ (%)	3-30	30-40	40-60	--	> 60
Gypsum (%)	0-5	5-10	10-20	--	> 20
Soil fertility characteristics (f):					
CEC [cmol (p^+) kg^{-1}]	> 16	8-16	< 8	--	--
B.S. (%)	> 50	50-35	< 35	--	--
O. C. (%)	> 0.6	0.4-0.6	< 0.4	--	--
pH	7.0-8.2	8.2-8.5	8.5-9.0	> 9.0	--
Salinity/alkalinity (n):					
ECe (dS m^{-1})	0-12	12-16	16-20	20-25	> 25
ESP	0-25	25-35	35-45	--	> 45

(g) Mustard					
1	**2**	**3**	**4**	**5**	**6**
Climatic (c):					
Precipitation (mm)	250-350	150-250	100-150	< 100	--
Mean temp. (°C)	20-28	18-20	16-18	< 16	--
Topography (t):					
Slope (%)	< 3	3-8	3-8	> 8	--
Wetness (w):					
Drainage	Moderate well drained	Imp./ somewhat excessive	Very low very excessive	--	--
Physical characteristic (s):					
Texture/Structure	cl-l	sl	ls	S	--
Coarse fragments (%)	< 15	15-35	> 35	--	--
Soil depth (cm)	> 75	75-50	50-25	< 25	--
$CaCO_3$ (%)	< 20	20-30	30-40	> 40	---
Gypsum (%)	< 3	3-5	5-10	> 10	--
Soil fertility characteristics (f):					
CEC [cmol (p^+) kg^{-1}]	> 16	8-16	< 8	--	--
B.S. (%)	> 560	35-50	< 35	--	--
O.C. (%)	> 0.4	0.2-0.4	0.1-0.2	--	--
pH	7.0-8.2	8.2-8.5	> 8.5	--	--
Salinity/alkalinity (n):					
ECe (dS m^{-1})	< 8	8-12	12-16	> 16	--
ESP	< 15	15-25	25-35	> 35	--

(h) Pearl millet					
1	**2**	**3**	**4**	**5**	**6**
Climatic (c):					
Precipitation (mm)	400-600	300-400	200-300	< 200	--
Mean temp. (°C)	20-28	18-20	16-18	< 16	--
Topography (t):					
Slope (%)	< 1-3	3-8	8-15	> 15	--
Wetness (w):					
Drainage	Well	Mod.	Imp.	Poor	Poor
Physical characteristic (s):					
Texture/Structure	c, cl, ft	cl-s, scl	ls, lfs, cl-s	fs, s	cs, s
Coarse fragments (%)	< 15	15-35	35-55	> 55	--
Soil depth (cm)	> 50	25-50	< 25	--	--
$CaCO_3$ (%)	0-25	25-35	35-50	> 50	--
Gypsum (%)	0-6	6-10	10-20	> 20	--
Soil fertility characteristics (f):					
CEC [cmol (p^+) kg^{-1}]	> 5	3-5	2-3	< 2	--
O.C. (%)	0.4	0.2-0.4	< 0.2	--	--
B.S. (%)	> 50	35-50	< 35	--	--
pH	7.0-8.2	8.2-9.0	> 9.0	--	--
Salinity/alkalinity (n):					
ECe (dS m^{-1})	< 4	4-8	8-12	> 12	--
ESP	< 25	25-35	35-45	> 45	--

S_1 = Highly suitable;
S_2 = Moderately suitable;
S_3 = Marginally suitable;
N_1 = Actually unsuitable but potentially suitable and
N_2 = Actually and potentially unsuitable.

Source: Sys *et al.*, (1991) and NBSS & LUP, (1994)

APPENDIX-II

Critical Levels of Key Indicators (Lal, 1994)

Limitations	Weighing factors	Effective rooting depths (m)	Bulk density (Mg m^{-3})	Consistency	Texture	Available water capacity (cm m^{-1})	Structure
None	1	> 150	< 1.2	Loose	Loam	> 30	Strong sub-angular blocky to crumb
Slight	2	100-150	1.2-1.3	Very friable	Silt-loam, silt, silty clay loam	20-30	Sub-angular blocky
Moderate	3	50-100	1.3-1.6	Friable	Clay loam, sandy loam	8-20	Moderate sub-angular blocky
Severe	4	25-50	1.4-1.5	Hard	Silty clay, loamy sand	2-8	Weak sub-angular blocky
Extreme	5	< 25	> 1.5	Hard to extremely hard	Clay, sand	< 2	Massive or single grain

Limitations	Weighing factors	pH (1:1 soil water suspension	EC (dS m^{-1})	O.C. (%)	ESP
None	1	7.0-7.4	< 3	5-10	< 15
Slight	2	7.4-7.8	3-5	3-5	15-30
Moderate	3	7.8-8.2	5-7	1-3	30-50
Severe	4	> 8.2	7-10	1-0.5	50-70
Extreme	5	--	7-10	< 0.5	--

Sustainability	Cumulative rating index
Highly sustainable	< 20
Sustainable	20 – 25
Sustainable with high input	25 – 30
Sustainable with alternate land use	30 – 40
Unsustainable	> 40

APPENDIX- III

List of alkali tolerant forest and fruit tree species

Average pH_2	Fuel wood/Timber species	Fruit trees
More than 10.0	*Prosopis spp.*	**Achrus japota**
	Acacia nilotica	
	Casuarina equisetifolia	
	Tamarix articulata	
9.0 to 10.0	*Terminalia arjuna*	*Punica granatum*
	Albizzia lebbek	*Zizyphus maurtiana*
	Pongamia pinnata	*Emblica officinalis*
	Sesbania sesban	*Carissa carandas*
	Eucalyptus tereticornis	*Psidium guava*
		Phoenix dactylifera
		Syzygium cumini
8.2 to 9.0	Dalbergia sissoo	*Pyrus communis*
	Morus alba	*Vitis vinifera*
	Grevillea robusta	*Mangifera indica*
	Azadirachta indica	
	Tectona grandis	
	Populus deltoides	

Source: Tyagi, (1996)