# CHARACTERIZATION OF SOILS OF AGRO-CLIMATIC ZONE OF SEMI-ARID EASTERN PLAIN OF RAJASTHAN

## राजस्थान के अर्द्ध शुष्क पूर्वी मैदानी भूमि के शस्य-जलवायु खण्ड की मृदाओं का गुण निर्धारण

KAMALESH KUMAR SHARMA

**THESIS**

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S. K. N. COLLEGE OF AGRICULTURE
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(RAJASTHAN)

D E D I C A T E D

TO MY

BELOVED PARENTS

SMT. AND SHRI R. L. SHARMA

# CHARACTERIZATION OF SOILS OF AGRO-CLIMATIC ZONE OF SEMI-ARID EASTERN PLAIN OF RAJASTHAN

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B Y
KAMALESH KUMAR SHARMA

APRIL, 1993

RAJASTHAN AGRICULTURAL UNIVERSITY : BIKANER

Dated 5/5/93

CERTIFICATE I

This is to certify that Mr. Kamalesh Kumar Sharma has successfully completed the comprehensive examination held on 30th October, 1992 as required under the regulations for the degree of Master of Science in Agriculture.

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CERTIFICATE II

This is to certify that this thesis entitled, "CHARACTERIZATION OF SOILS OF AGRO-CLIMATIC ZONE OF SEMI-ARID EASTERN PLAIN OF RAJASTHAN" submitted by Mr. Kamalesh Kumar Sharma for the degree of Master of Science in Agriculture in the subject of Soil Science and Agricultural Chemistry of the Rajasthan Agricultural University, Bikaner is a bonafide research work carried out under my 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.

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## CERTIFICATE III

This is to certify that this thesis entitled, "CHARACTERIZATION OF SOILS OF AGRO-CLIMATIC ZONE OF SEMI-ARID EASTERN PLAIN OF RAJASTHAN" submitted by Mr. Kamalesh Kumar Sharma to the Rajasthan Agricultural University, Bikaner in partial fulfilment of the requirements for the degree of Master of Science in Agriculture in the subject of Soil Science and Agricultural Chemistry has been approved by the Student's Advisory Committee after evaluation by the external examiner and an oral examination by the committee.

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CHARACTERIZATION OF SOILS OF AGRO-CLIMATIC ZONE OF SEMI-ARID EASTERN PLAIN OF RAJASTHAN

Kamalesh Kumar Sharma*

ABSTRACT**

Twenty-one soil samples from five profiles representing agro-climatic zone III-A of Rajasthan were collected and analysed for textural separates, physico-chemical properties, water soluble salts, cation exchange capacity and exchangeable cations. In addition, morphological studies of these soils were done to ascertain cause of development of these soils. The physical and chemical studies of soils were carried out to evaluate fertility status and to classify soils according to soil taxonomy, 1973.

The important findings of the present study are summarized as follows :

1. Soils of profile no. 1 are yellowish brown, loamy sand, very deep and well drained.

2. Soils of profile no. 2 are dark yellowish brown, loamy sand, non-calcareous, non-sodic, deep to very deep and moderately drained.

3. Soils of profile no. 3 are light yellowish brown to dark brown, loamy fine sand, deep to very deep and excessively drained.

4. Soils of profile no. 4 are yellowish brown to dark brown, sandy loam and moderately drained.

5. Soils of profile no. 5 are dark brown, fine sand and moderately drained.

6. Organic matter and available nitrogen content in most of the soil samples are low, whereas available phosphorus is medium to high and available potassium is medium.

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7. Calcium carbonate content of these soils show a trend of increase with depth in most of the profiles.

8. Soils under study are rich in water soluble ions. The dominating anions are chloride, followed by bicarbonate and sulphate whereas, sodium is predominating cation followed by calcium plus magnesium and potassium.

9. These soils are low in cation exchange capacity. Among the exchangeable cations, calcium predominates over magnesium, sodium and potassium.

On the basis of field observations and laboratory determinations, soils have been classified according to soil taxonomy, 1973 into following great groups :

| Profile No. | Location | Order | Sub-order | Great group | Sub-group |
|---|---|---|---|---|---|
| 1 | Jobner College farm | Entisol | Psamment | Ustipssamment | Typic Ustipssamment |
| 2 | Asalpur farm | " | " | " | " |
| 3 | A.R.S., Durgapura | " | " | " | " |
| 4 | A.R.S.S., Diggi | Alfisol | Ustalfs | Paleustalf | Typic Paleustalf |
| 5 | Roopangarh, Ajmer | Entisol | Psamment | Ustifluvent | Typic Ustifluvents |

# राजस्थान के अर्द्ध शुष्क पूर्वी मैदानी भूमि के शस्य जलवायु खण्ड की मृदाओं का गुण निर्धारण

कमलेश कुमार शर्मा*

## सारांश**

राजस्थान के शस्य जलवायु खण्ड III-अ के पाँच प्रतिनिधिक मृदा-परिच्छेदिकाओं से इक्कीस मृदा नमूनों को एकत्रित कर उसके संरचनात्मक कणों, भौतिकीय रसायन गुणों, जल में घुलनशील लवणों, धनायन विनिमय क्षमता और विनिमयशील धनायनों का विश्लेषण किया गया। इसके साथ में इन मृदाओं के विकास को जानने के लिए मृदा अकारिकी का अध्ययन किया गया। मृदा वर्गिकी विज्ञान, 1973 के अनुसार इन मृदाओं को वर्गीकरित करने के लिए तथा उर्वरता स्थिति का मूल्यांकन करने के लिए इन मृदाओं के भौतिक और रसायनिक गुणों का अध्ययन किया गया।

वर्तमान अध्ययन के महत्वपूर्ण अन्वेषणों को इस प्रकार से सार-गर्भित किया गया ।

1· परिच्छेदिका न· एक की मृदायें पीली-बादामी रंग की, बलुई-दुमट बहुत गहरी एवं पर्याप्त जल निकास वाली पायी गयी ।

2· परिच्छेदिका नं· दो की मृदायें गहरा पीलापन लिए बादामी रंग की, बलुई-दुमट, चूना रहित, क्षार रहित, गहरी से बहुत गहरी व मध्यम जल निकास वाली पायी गयी।

3· परिच्छेदिका नं· तीन की मृदायें हल्के पीले बादामी से गहरे बादामी रंग की, महीन बलुई - दुमट, गहरी से बहुत गहरी तथा विशेष जल निकास वाली पायी गयी ।

4· परिच्छेदिका नं· चार की मृदायें पीला बादामी से गहरे बादामी रंग की, बलुई-दुमट तथा मध्यम जल निकास वाली पायी गयी।

5· परिच्छेदिका नं· पाँच की मृदायें गहरे बादामी रंग की, महीन बालू तथा मध्यम जल निकास की पायी गयी।

6· कार्बनिक पदार्थ तथा प्राप्य नत्रजन का अंश अधिकतर मृदा नमूनों में न्यून रहा, जबकि प्राप्य फॉस्फोरस का अंश मध्यम से उच्च एवं प्राप्य पोटाश का अंश मध्यम पाया गया।

7· इन मृदाओं के अधिकतर परिच्छेदों में चूने का अंश गहराई के साथ-साथ बढ़ते हुए क्रम में दर्शाया गया ।

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8• अध्ययनरत मृदाओं में घुलनशील आयन अधिक पाये गये, ऋणायनों में क्लोराइड सबसे प्रमुख रहा तथा इसका अनुसरण बाई-कार्बोनेट व सल्फेट ने किया। जबकि धनायनों में सोडियम की प्रधानता रही तथं इसका अनुसरण कैल्शियम + मैग्नीशियम एवं पोटेशियम ने किया।

9• इन मृदाओं की धनायन विनिमय क्षमता न्यून रही, विनिमयशील धनायनों में मैंग्नीशियम, सोडियम एवं पोटेशियम पर कैल्शियम की प्रधानता रही ।

10• प्रक्षेत्र के अवलोकन तथा प्रयोगशाला विश्लेषणों के आधार पर एवं मृदा वर्गीकी विज्ञान, 1973 के अनुसार इन मृदाओं को निम्नलिखित समूहों में वर्गीकिरित किया गया है :-

| परिच्छेदिका नं• | स्थान | गण | उप-गण | वृहद-समूह | उप - समूह |
|---|---|---|---|---|---|
| 1• | जोबनेर कॉलेज फार्म | एन्टीसोल | सामेन्ट | अस्टिसामेन्ट | टिपिक अस्टिसामेन्ट |
| 2• | आसलपुर फार्म | एन्टीसोल | सामेन्ट | अस्टिसामेन्ट | टिपिक अस्टिसामेन्ट |
| 3• | ए•आर•एस• दुर्गापुरा | एन्टीसोल | सामेन्ट | अस्टिसामेन्ट | टिपिक अस्टिसामेन्ट |
| 4• | अ•आर•एस•एस•डिग्गी | एल्फीसोल | असटाल्फ | पेलुस्टाल्फ | टिपिक पेलुस्टाल्फ |
| 5• | रूपनगढ़ (अजमेर) | एन्टीसोल | सामेन्ट | अस्टिफिलेक्न्टस | टिपिक अस्टिफिलेक्न्टस |

# INTRODUCTION

Soil is one of the most important basic natural heritage of any country and it is indispensable for our existance. It nourishes the entire plant kingdom and supports human life.

Total area of the Rajasthan State is approximately 34.28 million hectares out of which approximately 16.77 million hectares are under cultivation. Agro-climatic zone III-A lies in the centre of eastern corner of Rajasthan. The area comprises of Jaipur, Ajmer and Tonk districts. This zone stretches over an area of 2.94 million hectares, which is 8.67 percent of the total geographical area of Rajasthan. The total cultivated area of this zone is 54.52 percent of the total area.

The area under study lies in the semi-arid region of Rajasthan and situated between 25.67° to 27.81° north latitude and 74.12° to 76.38° east longitude. The altitude ranges between 400 to 447 meters above mean sea level. The rainfall is seasonal, erratic and highly variable with respect to space and time and ranges between 500 to 600 mm annually.

The optimum plant growth and crop yield depends not only on the total amount of nutrients present in the soil at a particular time but also on their availability, which in turn is controlled by physical and chemical properties of the soils. The physical properties of soil influence plant growth through their effect on soil moisture, soil aeration, soil temperature, texture, structure, consistency and mechanical impedance to root development and shoot emergence.

The chemical properties like electrical conductivity, pH, soluble cations and anions, SAR, SSP, exchangeable cations and exchangeable sodium percentage also affect the plant growth. If salts are present in toxic amounts in the soil then proper plant growth will not take place. Thus, soil productivity is mainly governed by physico-chemical properties of the soil.

Systematic survey of soils of zone III-A has not been attempted. It is, therefore, important to describe and characterise the soils of this area. In order to suggest suitable management practices and remedial measures to tackle soil problems, both field and laboratory studies of the soils of the area are essential.

The objects of the study undertaken are :

1. To study the morphological, physical and chemical characteristics of the soils.

2. To determine fertility status of the soils.

3. To classify soils according to soil taxonomy.

# REVIEW OF LITERATURE

The relevant literature pertaining to the research problem is reviewed under the following heads :

2.1 Morphological properties of soils

2.2 Physical characteristics

2.2.1 Texture and structure

2.2.2 Apparent density

2.2.3 Porosity

2.2.4 Water holding capacity

2.2.5 Hydraulic conductivity

2.3 Chemical characteristics

2.3.1 Soil reaction, EC, ESP and SAR

2.3.2 Calcium carbonate

2.3.3 Water soluble salts and ESP

2.3.4 Organic carbon and CEC

2.4 Soils of Rajasthan

2.5 Classification of Rajasthan soils

2.6 Fertility status

## 2.1 Morphological properties of soils

Morphology of soil reflects some inherent properties of soils. Boul (1965) reported that in arid and semi-arid region the development of horizons are not clear since the process of translocations of fine material is restricted. The development of profile is influenced by parent material and counteracted by the physiography of the area and bio-climatic forces.

The prominent land forming features are wind and water action. The soils in general are deep with light textured surface layer, moderately fine to fine textured and surface horizons mixed with coarse fragments (Rajan <u>et al</u>., 1968) with in same climatic sub-division physiography.

Soils of sub-humid region generally showed a higher degree of weathering and formation of secondary products as observed by Saxena and Singh (1982). While, working on soils of Sarda river plain (U.P.) Singh <u>et al</u>. (1982) reported that development of calcareous loamy sendiments and morphology of soils is characterized by loamy fine sand texture, moderately well to imperfect profiles.

Bhatia <u>et al</u>. (1984) studies on soil morphology related to erodibility under different types of land use. They reported that erosiveness of the soil can be evaluated by the measurement of its loss in run off plots. Soils itself being an important factor in influencing erosion. It is a matter of particular interest in obtaining an index of erodibility by measuring some soil properties.

Singh et al. (1989) reported that the variation in soil colour have been attributed to differential characters of parent material. Grey coloured soils of the area exhibited brown, greyish brown to brownish grey colour. Poorly drained soils have a hue value of 2.5 YR with chroma around 2, micro morphologically medium to coarse structure in argillic horizons reflects in varying degree of plasm segregation. The impact of biogenic activity on soil structure is also evident by them.

Singh et al. (1991) studied the morphology and genesis of some soils of north-west Himalayas region. The soils have developed on Simla group of rocks overlain by infra-karol and karol series of the carboniferous lower mesozoic period under monsoon climate will have the undulating topography and peculiar natural drainage system. The soils have been classified in the orders Alfisol, Inceptisol and Entisol.

## 2.2 Physical characteristics

### 2.2.1 Texture and Structure

Soil texture is concerned with the size of mineral particles. Specially it refers to the relative proportion of the various size-groups in a given soil. But, the structure of a soil implies an arrangement of sand, silt and clay and of secondary particles (aggregates or structural elements) into a particular structural pattern.

Shukla et al. (1965) studied the profiles of foot hills of Himalayas for their morphological, physical chemical and mineralogical properties and found that the soils are brown loam, loam to clay and clay loam in texture. Viddappa and Venkatarao (1973) also observed elevation to have great influence on physical properties of soil.

Govind Rajan and Biswas (1968) revealed that the soils of the sub-tropical zone in south-eastern part of India are deep with light textured surface layer grading to moderately fine to fine textured sub-surface horizon mixed with coarse fragments.

Surface horizons of Kerala soils generally contained the maximum amount of clay which decreased with depth of the profile (Chandrashekharan and Koshy, 1970). Vyas (1973) evaluated that soils of Bilara tract (Rajasthan) were light in texture varying from sandy to sandy clay loam. Vyas et al. (1974) showed that the soils of Jaipur district (Rajasthan) were fairly good in physical condition as the texture of the soils varied from sandy to sandy loam. Soils of Pali district (Rajasthan) had been reported to range widely in their texture and most of these are loam to clayey in texture (Dhir and Bhatia, 1975).

Soil structure of the first horizon was highly correlated with the water intake, structure of the second horizon was next in order of importance followed by the nature of the boundary of first horizon (Rauzi and Fly, 1968).

As reported by Krishnamurty and Govind Rajan (1977) the soils of Udaipur valley are sandy loam to clay loam in texture and the soils are generally calcareous (Khangarot and Mehra, 1977). Similarly, soils of Sarda river flood plains of U.P. are characterized by loamy fine sand textures, sub-soils are moderately well to imperfect drainage (Singh et al., 1982).

2.2.2 Apparent density (BD)

Bulk density refers to the mass (weight) of a unit volume of dry soil. This volume would, of course, include both solids and pores.

Higher bulk density figures for cultivated and pasture soils than forest soils were observed by Yamamoto (1963). According to him the average available moisture was higher in forest soil as compared to the pastured soils. Ghildyal and Satyanarayana (1965) reported that over burden pressure increased micro-pores and hydraulic conductivity decreased that results as increase in bulk density.

Gradwell (1973) found that the bulk densities of lower top soils during the growing seasons were positively correlated with the dry bulk densities of aggregates.

Clay accumulation and high sodium saturation in sub-soils are correlated with increase in apparent density (Pandey and Pathak, 1975). Vyas et al. (1974) on the other hand concluded that apparent density of the soils of Jaipur district (Rajasthan) followed a trend of increase with depth. Mechanized cultivation and irrigation under paddy, wheat rotation increased the bulk density as reported by Sharma et al. (1974).

Kar *et al*. (1986) found an increase in bulk density of the 10-20 cm and 20-30 cm layers and consequent reduction in hydraulic conductivity of the soil, could be attributed due to burden of overlying strata. Furthermore, the increase in bulk density in lower layers could be caused due to burden of overlying strata.

### 2.2.3 Porosity

The pore space of a soil is that portion occupied by air and water. The amount of this pore space is determined largely by the arrangement of the soil particles. Vyas *et al*. (1974) investigated that pore space percentage of the soils of Jaipur district (Rajasthan) showed a trend of decrease with depth. In general these soils have fairly good pore space. Williams (1975) concluded that porosity (amount, distribution and continuity) is the most important single physical property of soil. Porosity affects the extent and patterns of root growth and therefore, the uptake of N, P and K.

Bullock *et al*. (1985) reported that the macro-porosity of soils was decreases with depth, Ledvina (1987) observed that changes in pore system of a secondarily hardened brown soil as a result of compaction, the pore system in the compacted layer is being degraded. They observed that the volume of non-capillary pores decreased as the capillary pores volume increased due to over burden pressure, thus, the soil air capacity decreased below the critical level.

### 2.2.4 Water holding capacity

Soils differ considerably in their moisture retention capacity. Fine textured soils retain much more water than coarse textured soils. The greater the aggregation, the larger is the amount of water held. Vyas et al. (1974) found that water holding capacity of soils of Jaipur district showed a definite trend of decrease with depth and they have fairly good water holding capacity in general. Talati et al. (1975) studied that the available moisture content was maximum in medium black soils followed by flood plain, desert plain, gypsiferrous and seirozem soils. A significant positive correlation was obtained individually between soil moisture content and silt and clay content.

Singh and Sharma (1984) found that water holding capacity of sand dunes of Jodhpur district varies from 20.0 to 26.3 percent. They also reported the physical aspects of two types of sand dunes viz. Longitudinal and parabolic and revealed that these dunes constitute more than 80 percent fine sand followed by coarse sand (2.2 to 10 percent) and 3.2 to 6.9 and 1.8 to 5.8 percent clay and silt, respectively.

### 2.2.5 Hydraulic conductivity

Hydraulic conductivity of soil was closely related to the physical characteristics of soil and it was very low due to presence of large amount of exchangeable sodium on exchange complex (Lole et al., 1970). Dixit and Lal (1972) investigated that an increase in exchangeable sodium percentage was accompanied by a marked decrease in hydraulic conductivity. The hydraulic conductivity of leached cinnamonic forest soil increases with increasing moisture content and with increasing compaction. The hysteresis effect on conductivity was greater when the soil was damp than when it was dry as reported by Koleva (1974). It has been observed by Sharma et al. (1974) that mechanical cultivation and irrigation under paddy-wheat rotation decreased hydraulic conductivity of the soils.

## 2.3 Chemical characteristics

### 2.3.1 Soil reaction, EC, ESP and SAR

A significant regression for electrical conductivity of saturation extract (ECe) of soils on the conductance of irrigation water in the profile at all depths was observed by Thorne and Thorne (1954) and they concluded that salt content of the soil was found to be closely related with salt content of irrigation water.

Lal (1970); Lal and Singh (1974) and Lal and Lal (1977) reported that the EC of saturation extract of sandy and loamy sand soils was less than EC of irrigation water. However, the extent of salt accumulation depends upon the degree of leaching. Similar results were also reported by Lal and Sharma (1975). The accumulation of salts was found to increase with increase in clay or clay + silt fraction in soil. There was positive correlation between soluble sodium percentage (SSP) of soils and RSC of irrigation water (Singh and Narain, 1979).

Richards (1950) concluded that increase in soil pH with an increase in ESP seemed to be fairly well established. Whereas, Fireman and Wedleigh (1951) indicated that the precision of prediction varies markedly depending on the geographical location of samples even of a single soil type. Richards (1950) had been of the view that local caliberation is necessary before pH can be used as an index of ESP. Positive correlation between pH values of irrigation water and soil suspension was observed by Paliwal and Gandhi (1973). Lal and Singh (1974) observed a decrease in pH values of the soil with an increase in the soluble salts concentration and an increase of pH with an increase in SAR of soil extract. Salt affected soils of Khaira district (Gujarat) were studied by Pathak and Patel (1980) and they found that salt accumulation is more in surface layer. The pH and ESP were comparatively higher in low layers, calcium carbonate content was noted to be more in salt affected areas.

2.3.2 Calcium carbonate

Roy et al. (1967) reported that calcium carbonate content in soils of Chotan block in Barmer district, Rajasthan was high, soluble salts were also very high, pH was in the range of 7 to 9 which increases with depth.

The calcium content was highest in surface soils of Kerala and it decreased down the profile while magnesium content of soil was inversely proportional to the rainfall (Chandrasekharan and Koshy, 1970). Soils of Etah and Mainpuri districts of U.P. have been worstly affected by both exchangeable sodium as well as excessive amounts of salt accumulation, as reported by Singh (1971). He further observed that the proportion of sodium salts was increasing gradually with the salt deposition.

The other important features of soils were high pH, low organic matter and varying hydraulic conductivity at the different layers in these soils. The $CaCO_3$ was also invariably present throughout profiles. Dhir et al. (1979) reported that 25 percent of the total geographical area of Pali block (Rajasthan) is having salinity and ranges from exclusively sodium chloride type to sodium-calcium chloride type. Distribution of salt affected lands appear to the down slope nature of the sites and poor surface drainage. In the irrigated soils, chloride and sulphate salts usually predominate, sulphate is much more highly hydrated in water than either chloride or nitrate.

Bhargava and Sharma (1982) reported that the soils of Indogangatic alluvial plain (North Bihar) are saline and wide spread strip of calcareous alluvial soils. The dominant salts occurring are the chloride and sulphate of sodium, magnesium and calcium and are deposited by continental geochemical cycles.

### 2.3.3 Water soluble salts and exchangeable sodium percentage

Vyas et al. (1973) noticed that soils of Jaipur district (Rajasthan) were rich in water soluble salts. The dominating anions are chlorides, sulphates and bicarbonates.

In some of the profiles or horizons the carbonate was totally absent. Water soluble sodium was predominating cation and next dominating cations were calcium plus magnesium followed by potassium.

Abrol et al. (1978) studied the effect of exchangeable sodium on some physical properties of sandy loam soil and observed that with an increase in ESP, the moisture retention increased at soil water suction greater than about 0.2 atmosphere. Infiltration rate, soil water storage and soil water diffusivity underwent a sharp decrease when ESP was higher than 15.

2.3.4 Organic carbon and CEC

A positive correlation between organic carbon and CEC of the soils of Rajasthan was found by Singh and Lal (1968). According to them, 1 percent change in organic carbon of these soils was equivalent to 4.7 meq CEC per 100 gm of soil. Lavati et al. (1969) also observed that the CEC of soils of Rajasthan was significantly correlated with clay, silt and organic matter content. Vyas et al. (1974) recognised that soils of Jaipur district (Rajasthan) were low to medium in CEC. Among the exchangeable cations sodium predominates. No definite trend was noticed regarding CEC and exchangeable cations with depth.

Biddapa and Rao (1973) reported increase in nitrogen content and CEC with simultaneous decrease in pH and soluble silica with increase in rainfall and elevation. A comparative study of soil development on the Gangetic alluvium of U.P. under cultivation was carried out by Ghildyal et al. (1962) and they revealed that there had been translocation of iron, Mg and their accumulation in the lower horizon under continuous cropping. Calcium leached from upper horizons and accumulated in lower horizons as semi-indurated large calcareous nodules. While studying the Ajmer soil, Tamhane et al. (1953) reported upward leaching of silica as shown by the decrease of silica alumina ratio of the clay fraction with depth.

Vyas et al. (1982) studied on six representative sites irrigated with saline waters in Bilara tract (a south-eastern part of Jodhpur district of Rajasthan) were chosen for pedon sampling alongwith their irrigation water and analysed for different constituents. The soils have high EC and ESP and are saline alkali and alkali in character. The irrigation waters are sodic and possess high SAR and SSP values. Irrigation waters are the source of soluble salts in these soils. EC of the waters is significantly related to the EC of saturation extract of soils as also the SAR of waters and soil extracts.

## 2.4 Soils of Rajasthan

Till the year (1952) not much informations was available on soils of Rajasthan. First attempt to group the soils of the state was made in 1958 by compiling the available information. This was modified from time to time as the knowledge about soils of the state developed.

The soils of Western Rajasthan are described as very sandy, but not inert and infertile (Gupta, 1958). However, some of the soils contain high percentage of soluble salts, possess high pH, low loss of ignition, varying percentage of calcium carbonate and are poor in organic matter (Raychoudhary, 1952). Scarcity of water is the main limitation in these regions. The soils are highly susceptible to wind. Rajasthan state has all types of saline and alkali problems constituting roughly 15 percent of cultivated area and the saline water problem is more intensive in Western Rajasthan (Mehta, 1962; Mathur, 1968; Mehta, 1971).

Soils are poor in nitrogen, medium in phosphorus and medium to high in potash. Soils are coarse textured and less productive (Sharma et al, 1968). The most common characteristics of the soils of Indian desert is their poor fertility status with a zone of lime precipitation in the sub-soil. They are deep, structure-less and porous. The soils are, further, characterised by incomplete leaching of soluble salts, ill defined profile development and very poor in humus content (Jain, 1968).

Choudhary and Dhir (1982) studied the dunes and associated sandy plain soils of eastern plain and western Rajasthan and reported the characters of dunes at different depths of 0 to 50 cm, 50-100 cm and 100-150 cm. The pH of soils were 8.4, 8.35 and 8.35; the coarse clay percent were 0.62, 0.87 and 0.90, the fine clay percent were 1.33, 1.0 and 1.29 respectively.

Development of profiles of two aridosols on two distinct rock formation regions on degraded alluvial plain was studied by Choudhary (1988) and observed that morphology of both the profiles showed well aggregated dark brown B-horizon with appreciably more clay with well formed lime segregation.

2.5 Classification of Rajasthan soils

The land assessment classification of Revenue Department mainly based on irrigation facilities and socio-economic considerations was the one followed for soils of Rajasthan. Few categories were as follows : Barani (Rainfed soils), Chahi (well irrigated soils), Nahri (Canal irrigated soils), Sailabi (Moistened by river seepage), Oran (General grazing lands) etc. The systematic soil classification work was taken up after the formation of the state. Since than few attempts were made to classify these soils as presented here.

Raychoudhary (1964) divided soils of Rajasthan based on their occurrence, chief characteristics and suitability for cultivation into the following seven groups : 1. Desert soils, 2. Grey and brown (desert) soils, 3. Red and yellow soils, 4. Ferruginous red soils, 5. Mixed red and black soils, 6. Medium black soils, and 7. Alluvial soils.

Satyanarayana (1964) 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 salts

Class III : Areas intercepted by sand dunes

Class IV : Sand dunes area

Class V : Flat area with gypsum pan after 3-4"

Class VI : Kankar area

Roy and Sen (1968) classified soils of Rajasthan according to 1938 system and presented soil map of the state showing occurrence and distribution of various soil types. The schematic classification and grouping of Rajasthan soils into old system of soil classification is given below :

Table 1 : The position of soils of Rajasthan in the whole system of soil classification.

| Order | Sub-order | Great soil group | Great group which occurs in Rajasthan |
|---|---|---|---|
| 1. zonal | 1) Soils of the cold zone | Tundra | - |
| | 2) Light coloured podzolised soils of timbered regions | Podzol soils, brown podzolic soils, grey brown podzolic soils red-yellow podzolic soils, grey-podzolic or grey wooded soils | - |
| | 3) Soils forested warm temperate and tropical region | A variety of latosols are recognised. They await detailed classification | - |
| | 4) Soils of forest grassland transition | Degraded chernozem soils, non-calcic brown or shantung brown soils. | - |
| | 5) Dark coloured soils of semi-arid, sub-humid and humid grassland. | Prairic soils, reddish prairic soils, chernozem soils, chestnut soils, reddish chestnut soils | - |

| | | | |
|---|---|---|---|
| | 6) Light coloured soils of arid regions. | Brown soils, Sierozeme soils, Red desert soils | Brown soils, saline phase. Sierozem red desertic soils |
| 2. Intra-zonal | 1) Hydromorphic soils of marshes swamps flats and seepage areas. | Humic-glay soils, Alpine meadow soils, Bog soils, Half bog soils, Planosole, Ground water podzols, Ground water latosols. | - |
| | 2) Halmorphic (Saline and alkali) soils of imperfactly drained arid regions, Litoral deposits. | Solanchake(saline soils). Solonetz soils (alkali soils) soloth soils. | Saline soils of depression. |
| | 3) Calcic imorphic soils. | Brown forest soils, Rendzina soils. | Red loam |
| 3. Azonal | No suborders | Lithosols | Red and yellow soils, Yellowish brown soils of foot hills. |
| | | Regosols(includes dry sands) | Desert soils, sand dunes. |
| | | Alluvial | Old alluvium not recent alluvium black soils. |

Mathur et al. (1968) classified soils of Rajasthan based on a broad reconnaissance survey into following eight groups : 1. Desert soils, 2. Grey brown soils, 3. Grey brown soils of river basin, 4. Undifferentiated alluvial soils, 5. Mixed red and black soils, 6. Red loam (shollow soils), 7. Medium black soils, and 8. Red and yellow soils.

Soils of Rajasthan have been grouped into 12 associations based on a broad reconnaissance survey by Mehta et al. (1970) :

1. Desert soil
   a) Calcic brown soil
   b) Non-calcic brown soil
   c) Sand dunes
2. Desert riverine soil
3. Alluvial sierozems
4. Grey brown soil gypsiferous or calcareous
5. Non-calcic brown soil
6. Brown soil saline phase
7. Alluvial soil of recent origin
8. Grey brown alluvial soils
9. Yellowish brown soils
10. Red loam
11. Medium black soils
12. Hilly soils

Soil survey organisation of Rajasthan (Mathur et al., 1974) classified soils of Rajasthan according to soil taxonomy under 5 orders viz., Aridisols, Alfisols, Entisols, Inceptisols and Vertisols. Soils have been grouped at sub-order and great group level under these orders. This classification upto great group level has been shown on the map. Approximation equivalents of old and new system of soil classification is given below :

Table 2. Classification of Rajasthan soils according to soil taxonomy.

| S.No. | Order | Sub-order (New comprehensive system) | Great group | Approximate equivalent in the old system (1949) |
|---|---|---|---|---|
| 1. | Aridisols | Orthids | Camborthids<br>Calciorthids<br>Salorthids<br>Paleorthids | Seirozems,<br>Desert soils,<br>Saline soils of depression |

| | | | |
|---|---|---|---|
| 2. Alfisols | Ustalfa | Haplustalfs | Red loam, black soils, brown soils, yellowish brown soils of foot hills, alluvial soils |
| 3. Entisols | Psamments | Torripsamments Quartzipsamments | Desert soils and sand dunes |
| | Fluvents | Torrifluvents Ustifluvents | Alluvial soils (old and recent) |
| 4. Inceptisols | Orchrepts | Ustochrepts | Brown soils, red and yellow soils of foot hills |
| 5. Vertisols | Usterts | Chromusterts Pellusterts | Black soils |

Karan (1975) classified soils of western and central plain of Rajasthan according to soil taxonomy. He has recognized following important nine groups :

<u>Normal soils</u> - Typic Haplargids
- Typic Camborthids
- Pluventic Camborthids
- Psammentic Camborthids
- Typic Torripsamments
- Fluventic Torripsamments

<u>Problematic soils</u> - Typic Natrargids
- Natric Salorthids
- Torrifluventic Salorthids

Choudhary *et al*. (1989) also classify the soils on the basis of erodibility indices and concluded that surface samples of benchmark soils are sandy loam texture, without any problems of salinity and/or alkalinity. The high erosion ratio indicate the erodible nature of the soils. Water holding capacity and moisture equivalent are correlated positively, and dispersion ratio and erosion ratio negatively with finer fraction of soils.

2.6 Fertility status

Storie (1950) devised one of the earliest methods of productivity ratings. The system rated lands on the basis of ten soil characteristics as signified by four factors viz.,

(A) Soil profile characteristics (depth and permeability)

(B) Texture (surface texture and structure)

(C) Slope of land

(D) Miscellaneous characteristics that may be modified by management (drainage, toxic conditions, fertility, erosion and micro-relief).

The index was calculated by multiplying the evaluated values for each factor and was expressed in percentage. According to the index calculated, various soils were grouped into six grades.

Shome and Raychoudhary (1960) selected three factors for evaluating the productivity rating index.

1. Factor A - Permeability, degree of weathering and natural fertility.
2. Factor B - Topography, texture and structure.
3. Factor C - Degree of climatic suitability, salinity, alkalinity, stoniness and tendency to erode.

Sanghi et al. (1976) analysed the 4922 soil samples of desert soils of Rajasthan. Data indicates that the soils are very low, tending towards medium in organic carbon, available phosphorus and potassium contents respectively. Choudhary and Jain (1979) studied the distribution of different forms of K and K-fixing capacity in the soils different agro-climatic regions of Rajasthan. Water soluble and exchangeable K were highest in soils of arid and transitional regions.

Joshi and Ghonsikar (1981) enunciated 8 profiles representing different soil group in Rajasthan and reported that total phosphorus content varies from 80 to 540 ppm. Desert soils of medium to coarse textures are low in organic matter content but contained higher amount of total phosphorus. Organic phosphorus was found in range from 76 to 340 ppm.

Joshi et al. (1982) studied the 32 surface soil samples from major soil groups of arid and semi-arid regions of Rajasthan and reported that mean values of HCl soluble ($N/HNO_3$ soluble), fixed and available K forms in dune and interdunal sand, light brown sandy and brown light were low than the grey brown soils. The dune and interdunal soils showed negative K fixation because of very low clay content.

Lateron, Joshi and Dhir (1983) analysed 118 soil samples from 37 soil profiles representing recognised soils series/ groups in the Jaisalmer, Jodhpur, Jaipur, Ajmer and Nagaur districts and reported that the soils are very low in organic carbon 0.03 to 0.45 percent and neutral to alkaline in reaction (pH 7.0 to 9.2). About 50 percent soil samples showed sand to loamy sand texture having less than 16 percent silt + clay. $CaCO_3$ was less than 1 percent in 50 percent of soil sample and only 25 percent samples contained more than 4 percent $CaCO_3$.

Vinod Kumar and S.P. Seth (1983) studied on soil fertility status of Rajasthan State were undertaken at soil testing laboratory, Sri Ganganagar (Rajasthan). It was observed that on and average soils were not problematic with respect to salinity and alkalinity. Soils were low in organic carbon and medium to high in available phosphorus and available potash. The nutrient status with respect to N, P and K has been distinguished on panchayat samiti basis and fertilizer recommendations for various fertility groups have been given.

<u>Direct rating from soil test data</u>

Muhr *et al*. (1965) reported the procedure used for the fertility rating of soils by soil testing laboratories in India. The rating system is presented below :

Table 3. Interpretation of classes by Muhr *et al*. (1965)

| Nutrient | Low | Medium | High |
|---|---|---|---|
| I. Organic carbon (as a measure of available N) | $<0.5$ % | 0.5-0.75% | $>0.75$% |
| II. Available P | $<11.2$ kg/ha | 11.2-25.0 kg/ha | $>25$ kg/ha |
| III. Available K | $<120$ kg/ha | 120-280 kg/ha | $>280$ kg/ha |

The rating system is widely used for the purpose of grouping soils according to fertility status all over India.

Fertility status of soils of Rajasthan

On the basis of general fertility survey soils of Rajasthan have been grouped into five groups according to Department of Agriculture, Rajasthan.

| Group | Available Nitrogen | Available Phosphorus | Available Potash |
|---|---|---|---|
| I | Low | Medium | Medium |
| II | Low | High | Medium |
| III | Medium | Medium | Medium |
| IV | Medium | High | Medium |
| V | Medium | Medium | High |

According to Department of Agriculture, Rajasthan, the soils of Rajasthan have been classified into seven fertility groups based on the analytical data. The name of the district alongwith the fertility group are given below :

Table 4. Fertility grouping of Rajasthan soils based on analytical data.

| S.No. | Name of the district | Fertility group | | |
|---|---|---|---|---|
| | | Available N | Available P | Available K |
| 1. | Ajmer, Alwar, Bikaner, Kota, Pali, Bharatpur, Jaipur, Jodhpur, Jhunjhunu, Nagaur, Sirohi, Churu | Low | Medium | Medium |
| 2. | Tonk, Banswara, Bhilwara, and Chittorgarh | Medium | Medium | Medium |
| 3. | Bundi and Jaisalmer | Low | Low | Medium |
| 4. | Barmer, Sriganganagar, Jalore and Jhalawar | Low | Medium | High |
| 5. | Udaipur | Medium | Medium | High |
| 6. | Dungarpur and Sikar | Low | High | Medium |
| 7. | Sawai Madhopur | Low | High | Medium |

On the basis of analysis, the fertility map of Rajasthan has been prepared. The fertility map indicates that out of 29 districts in Rajasthan, the soils in 21 districts are deficient in nitrogen while phosphorus is low only in two districts namely Bundi and Jaisalmer. The potash status ranges from medium to high in Rajasthan.

## MATERIALS AND METHODS

Five soil profiles were dug and samples according to the method described in the soil survey manual (Soil Survey Staff, 1966) to characterize the soils of Agro-climatic zone III-A in Rajasthan. A general description of the area and brief account of the profiles studied is given in the succeeding pages.

### Description of the study area

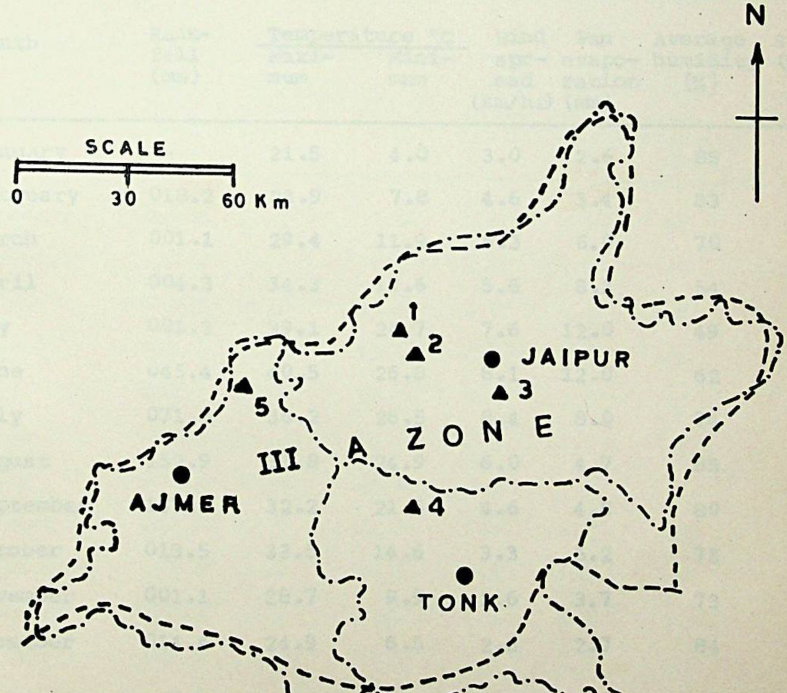
### 3.1 Location

The most significant physical property of an area is its location. The area studied lies in the semi-arid region of Rajasthan. It is situated between 25.67° to 27.81° of north latitude and 74.12° to 76.38° of east longitude, having a total area of 2.94 million hectares. The altitude of the zone III-A ranges between 400 to 447 meters above mean sea level. The agro-climatic zone III-A is located (surrounded) by district Sikar in north, Bhilwara and Bundi in south, Alwar and Dausa in east and Nagaur district in west.

### 3.2 Geology

The soils have developed from recent and sub-recent local alluvium of metamorphic and igneous origin soils from Aravallis. But at few localities of the agro-climatic zone III-A includes coastal and littoral alluvium and aeolian sand. The geology of this area have developed in aeolian alluvial materials on nearly level to gently sloping lands at an elevation of 400 to 447 meters above mean sea level.

FIG._1. MAP OF SEMI ARID EASTERN PLAIN IN RAJASTHAN SHOWING PROFILE SITES




INDEX

1_ JOBNER
2_ ASALPUR FARM
3_ ARS DURGAPURA
4_ ARSSDIGGI
5_ ROOPANGARH

ZONE_III A BOUNDARY - - - - -
DISTRICT BOUNDARY -.-.-.
DISTRICT HEADQUARTER ●
PROFILE SITES ▲

Table 5 : Distribution of mean monthly rainfall, temperature (maximum and minimum), wind speed (km/hr), pan evaporation (mm), average humidity and sunshine of Jobner College Farm, Jaipur (January 1991 to December, 1992).

| Month | Rain-fall (mm) | Temperature °C | | Wind spr-ead (km/hr) | Pan evapo-ration (mm) | Average humidity (%) | Sunshine (hrs/day |
|---|---|---|---|---|---|---|---|
| | | Maxi-mum | Mini-mum | | | | |
| January | - | 21.5 | 4.0 | 3.0 | 2.6 | 85 | 08.7 |
| February | 018.2 | 23.9 | 7.8 | 4.6 | 3.4 | 83 | 08.8 |
| March | 001.1 | 29.4 | 11.9 | 5.3 | 6.0 | 70 | 08.3 |
| April | 004.3 | 34.3 | 17.6 | 5.6 | 8.3 | 54 | 09.9 |
| May | 002.3 | 39.1 | 24.7 | 7.6 | 12.0 | 49 | 09.5 |
| June | 045.4 | 40.5 | 26.8 | 8.1 | 12.0 | 62 | 09.6 |
| July | 071.8 | 36.2 | 26.5 | 8.4 | 8.0 | 74 | 06.3 |
| August | 152.9 | 31.8 | 24.9 | 6.0 | 4.7 | 85 | 05.4 |
| September | 137.5 | 32.2 | 21.6 | 4.6 | 4.8 | 80 | 08.9 |
| October | 013.5 | 33.5 | 14.6 | 3.3 | 5.2 | 73 | 09.4 |
| November | 001.1 | 28.7 | 9.9 | 2.6 | 3.7 | 73 | 08.8 |
| December | 014.4 | 24.9 | 6.5 | 2.3 | 2.7 | 84 | 07.9 |

Table 6 : Distribution of mean monthly rainfall, temperature (maximum and minimum), wind speed (km/hr), pan evaporation (mm), average humidity, and sunshine of A.R.S., Durgapura (Jaipur) (January, 1991 to December, 1992)

| Months | Rain-fall (mm) | Temperature °C | | Wind speed (km/hr) | Pan evapo-ration (mm) | Aver-age humidity (%) | Sunshine (hrs/day) |
|---|---|---|---|---|---|---|---|
| | | Maxi-mum | Mini-mum | | | | |
| January | 013.8 | 21.0 | 7.8 | 2.8 | 2.7 | 64 | 07.3 |
| February | 002.1 | 24.7 | 9.8 | 3.8 | 3.7 | 70 | 08.5 |
| March | 005.2 | 27.8 | 13.8 | 4.0 | 5.2 | 48 | 07.5 |
| April | 001.2 | 34.7 | 19.1 | 5.7 | 5.7 | 41 | 09.4 |
| May | 000.4 | 40.2 | 25.5 | 7.4 | 11.3 | 46 | 09.1 |
| June | 021.4 | 36.2 | 24.7 | 8.4 | 11.3 | 49 | 07.7 |
| July | 258.8 | 36.0 | 25.9 | 8.8 | 7.9 | 73 | 05.7 |
| August | 260.0 | 29.9 | 22.3 | 5.8 | 3.2 | 77 | 03.5 |
| September | 147.0 | 31.5 | 20.3 | 5.6 | 4.3 | 68 | 07.1 |
| October | 002.0 | 32.4 | 17.5 | 4.6 | 3.4 | 58 | 08.1 |
| November | 002.0 | 27.6 | 12.5 | 3.8 | 2.8 | 68 | 07.8 |
| December | 018.0 | 24.4 | 10.1 | 3.7 | 2.4 | 74 | 08.0 |

## 3.3 Climate

Rainfall and temperature are the two main elements of the climate. The climate of this region is typically semi-arid which is characterized by extremes of the temperature both during summer and winter. In summer maximum temperature ranges between 36°C to 48°C whereas in winter the temperature falls down to as low as -5°C in the month of January. The rainfall is seasonal, erratic and highly variable with respect to place and time and it ranges between 457 to 600 mm annually which is mostly received during the monsoon lasting from July to September. Rainy season begins from middle of June and starts retreating around the end of September and it is characterized by hot and wet periods when maximum weathering of soils is expected to take place in the area.

## 3.4 Natural vegetation

Natural vegetation affects profile differentiation by furnishing organic matter, by adsorbing and recycling plant nutrients by producing roots and supplying a cover to the surface (Barshad, 1964). The nature of organic matter with respect to its organic and inorganic composition, as affected by plant species and environment is a important factor for profile differentiation. It is, therefore, desirable to add information on natural vegetation of the study area.

Most of the study area is under cultivation and the information about natural vegetation of the area is collected from uncultivated tract in the near vicinity of the profiles and from total zone III-A.

A. The most common trees growing in the study area are : Babool (Acacia arabica), Vilayati Babool (Prosopis juliflora), Khejri (Prosopis cineraria), Khair (Acacia catechu), Neem (Azadirachta indica).

B. Common shurbs and bushes of the area are : Aak (Calotropis procera), Dhatura (Dhatura metel), Khemp (Leptadenia pyrotechnica), Munja (Saccharum munja), Dhamasa (Tephrosia sarphonlea) Jawasa (Alhagicome-lorum) and Ber (Ziziphus jujuba).

C. Common grasses of the area are : Cenchrus setigerus, Avena fatua, Cynodon dactylon, Phalaris minor, Panicum antidotale.

D. Main crops of the area are : Bajra (Pennisetum typhoideum), Maize (Zea mays), Jowar (Sorghum vulgare), Cowpea (Vigna sinensis), Guar (Cyamopsis spp.) Moong (Vigna radiataL), in Kharif and Wheat (Triticum aestivum), Barley (Hordeum vulgare), Mustard (Brassica juncea), Raya (Brassica nigra) etc. in Rabi.

## 3.5 Soils

The soils of agro-climatic zone III-A (Rajasthan) shows some variations. It is primarily alluvial and calcareous and also contain gravels. The texture is loamy sand to loamy fine sand. In this area various soil classes, like coarse light soils, dark medium heavy soils, yellowish brown soils and brown medium soils have been observed.

Most of the soils of this area are well washed and shows low to medium fertility status. pH of the soils is more than 7.4. In the vicinity of the study area saline and saline-sodic soils were observed and most of the area is suffered from salinity and sodicity hazards.

3.6 Survey and sampling

The area was first surveyed to prepare a reconniass-ance map of the farm. The boundaries were delineated and mapped.

Soils were examined by taking systematic auger bore samples at five profile sites. Auger bore samples were examined upto a depth of one meter and were examined for colour, texture and calcium carbonate.

Surface features like slope, erosion and field conditions were recorded during traverses. On the basis of recorded inform-ations representative soil profile site were selected and pits were dug to a depth of over 170 cm or upto 'C' horizon, whichever was shallower. Five representative profiles were examined as described above.

Morphological description including identification and nomenclature of horizons recorded in the fields are according to the procedure given by USDA soil survey manual (Hand book No.60) and soil survey manual of India.

From each horizon approximately four kg soil was collected in cloth bags and properly labelled. Soil samples were air dried, grinded with a wooden roller and passed through a

2 mm sieve and then soil material (< 2 mm) was stored in cloth bags for the laboratory analysis. Coarse skeleton (> 2 mm) was also collected, washed, dried and weighed to calculate its percentage.

For fertility evaluation of soils every profile site was considered as an individual unit and composite samples were collected from 15 cm layer (plough layer) using the techniques recommended by soil testing in India (Muhr et al., 1965). These samples were air dried, crushed and sieved through 0.5 mm sieve and used for analysis of available nutrients. The methods followed for various physical, chemical and physico-chemical determinations are given in Table 8.

Table 7. Methods of soil analysis.

| S.No. | Properties | Methods | References |
|---|---|---|---|
| 1. | Physical properties | | |
| | A. Particle size analysis | International Pipette method | Piper (1950) |
| | B. Apparent density (Bulk density) | Core sampler method | USDA Hand book No.60 (Richards, 1954) |
| | C. True density (Particle density) | R.D. Bottle | USDA Hand book No.60 (Richards, 1954) |
| | D. Total porosity | Calculated by using the formula $\text{Percent pore space} = \frac{\text{True density} - \text{Apparent density}}{\text{True density}} \times 100$ | USDA Hand book No.60 (Richards, 1954) |
| | E. Water holding capacity | Keen-Reczowasky box method | Piper(1950) |
| | F. Colour | By Munsell soil colour chart | - |

| | | |
|---|---|---|
| 2. Chemical properties | | |
| A. Organic carbon | Walkley and Black's wet digestion method | Piper (1950) |
| B. Calcium carbonate | Acid neutralization method | Allison and Moddie (1965) |
| Water soluble cations and anions | | |
| C. Soluble $Na^+$ and $K^+$ | Flame photometer | Richards (1954) |
| D. Soluble $Ca^{2+}$+$Mg^{2+}$ | Versenate titration | Richards (1954) |
| E. Chloride | Silver nitrate | Richards (1954) |
| F. Carbonate and bi-carbonate | Acid titration | Richards (1954) |
| G. Sulphate | Precipitation by Barium chloride EDTA method | Richards (1954) |
| 3. Physico-chemical analysis | | |
| A. pH | Beckman pH meter | USDA Hand book No.60(Richards, 1954) |
| B. Cation exchange capacity | Schollenburger's ammonium acetate method | Richards (1954) |
| C. Electrical conductivity | Using standard precision solubridge | Richards (1954) |
| D. Exchangeable $Ca^{2+}$ | Versenate titration method | USDA Hand book No.60(Richards, 1954) |
| E. Exchangeable $Mg^{+2}$ | Versenate titration method | USDA Hand book No.60(Richards, 1954) |
| F. Exchangeable $Na^+$ and $K^+$ | By neutral normal ammonium acetate extract method | USDA Hand book No.60(Richards, 1954) |
| G. Exchangeable sodium percentage | Calculated by using the formula : | USDA Hand book No.60(Richards, 1954) |

$$ESP = \frac{\text{Exchangeable } Na^+ (\text{C.Mol kg}^{-1} \text{ of soil})}{\text{CEC(C.Mol kg}^{-1} \text{ of soil)}} \times 100$$

| | | |
|---|---|---|
| H. Sodium adsorption ratio | Calculated by using the formula : | USDA Hand book No.60(Richards, 1954) |

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

| | | |
|---|---|---|
| I. Soluble sodium percentage | Calculated by using the formula : | USDA Hand book No.60(Richards, 1954) |

$$SSP = \frac{\text{Soluble Na (meq/l)}}{\text{Total soluble cation ( meq/litre)}} \times 100$$

4. **Fertility status**

| | | |
|---|---|---|
| A. Available nitrogen | Alkaline permanganate method | Subbiah and Asija (1956) |
| B. Available phosphorus | Colour of $SnCl_2$ measurement by colorimeter method | Olsen (1954) |
| C. Available potassium | Normal neutral ammonium acetate extraction method | Honeway and Heidal(1952) |

## 3.7 Statistical analysis

To find out the relationship between the different characteristics of soil properties horizon-wise, the coefficient of correlation was determined by using the formula :

$$r = \frac{SP\ (X.Y)}{\sqrt{SS\ (X),\ SS\ (Y)}}$$

# RESULTS AND DISCUSSION

In the present investigation soils of agro-climatic zone III-A of semi-arid eastern plain in Rajasthan were studied with the object of characterization of soils. More emphasis has been given on morphological features of the soils, according to soil taxonomy and soil fertility.

Field and laboratory studies have been carried out and the results obtained are discussed under the following heads :

4.1 Morphological characteristics of soil

4.2 Laboratory studies

- 4.2.1 Physical characteristics of soil
- 4.2.2 Analysis of saturation extract
- 4.2.3 Cation exchange capacity and exchangeable cations
- 4.2.4 Fertility status of soil

4.3 Classification of soils according to Soil taxonomy, 1973

4.4 Correlation between various properties of soils.

## 4.1 Morphological characteristics of soil

According to field observations soils vary in colour, texture, structure, consistency and other important morphological features. Colour varies from light yellowish brown to brown and strong brown and texture varies from loamy sand to fine sand.

A clear distinct ochric epipedon was observed in almost all profiles. Cambic and argillic horizons were identified in sub-surface. Soils are shallow to deep and moderately drained. Soils are deep and moderately developed with distinct horizonation (Profile No. 1,3,4,5) except the soil profile number 2, where profile development is poor.

Details of morphological features of profiles under study are given below :

Morphology of the profiles

PROFILE NO. 1

| | | |
|---|---|---|
| Location | - | Well No.10, Agronomy Farm, SKN College of Agriculture, Jobner |
| Present land use | - | Cultivated |
| Agro-climatic zone | - | III-A |
| Climate | - | Semi-arid |
| Slope | - | 2 percent |
| Drainage | - | Well drained |
| Order | - | Entisol |
| Sub-order | - | Psamment |
| Great group | - | Ustipssamment |
| Soil series | - | Chomu series (Tentative) |
| Thermo-regime | - | Hyperthermic |

| Horizon | Depth (cm) | Description of the profile |
|---|---|---|
| $A_p$ | 0-53 | Brownish-yellow colour (10 YR 6/6) when dry and Yellowish-brown (10 YR 5/6) when moist, loamy sand, single grain, loose and friable when dry, sub-angular blocky, structure, granular, non-sticky and non-plastic, abundent roots, no effervescence with dilute HCl, regular boundary, pH 8.2, |

| | | |
|---|---|---|
| $A_1$ | 54-80 | Yellowish-brown (10 YR 5/6) when dry and dry yellow (10 YR 4/4) when moist, loamy sand, loose and friable, granular, sub-angular blocky structure, very few fine roots, no effervescences with dilute HCl, regular boundary, pH 7.8. |
| $A_2$ | 80-127 | Yellowish-brown (10 YR 5/6) when dry and moist, loamy sand, loose and friable when dry, granular and sub-angular blocky, structure, no concretion, few fine roots, pH 8.1, slight effervescences with dilute HCl, regular boundary. |
| $B_1$ | 127-160 | Dry yellow (10 YR 4/4) when dry and moist, loamy sand, no concreation, loose and friable when dry, sub-angular blocky structure, few fine roots, pH 7.8, slightly sticky, no effervescences with dilute HCl, regular boundary. |
| $B_2$ | 160-200 | Dry yellowish brown (10 YR 4/4) when dry and moist, loamy sand, no calcium carbonate deposites, granular, sticky consistancy when moist, loose and friable when dry, sub-angular blocky structure, no concretion, roots absent pH 8.1, slightly hard and firm when dry, no effervescence with dilute HCl, regular boundary. |

| | | | |
|---|---|---|---|
| Vegetation : | Khejri | - | Prosopis cineraria |
| | Neem | - | Azadirachta indica |
| | Ber | - | Ziziphus jujuba |
| | Dhamasa | - | Tephrusia sarphonlea |
| | Aak | - | Calotropis procera |
| | Babul | - | Acacia arabica |
| | Doob | - | Cynondon dactylon |

PROFILE NO. 2

| | |
|---|---|
| Location | - Asalpur (Jobner)<br>Asalpur Farm |
| Present land use | - Pomegranate cultivation |
| Agro-climatic zone | - III-A |
| Climate | - Semi-arid |
| Slope | - 3 percent |
| Drainage | - Moderate |
| Order | - Entisol |
| Sub-order | - Psamment |
| Great group | - Ustipssamment |
| Soil series | - Chomu series (Tentative) |
| Thermo-regime | - Hyperthermic |

| Horizon | Depth (cm) | Description of the profile |
|---|---|---|
| A | 0-38 | Yellowish brown (10 YR 5/4) when dry and moist, loamy sand, no mottling, single grain, loose and friable when dry sub-angular blocky structure, granular, non-sticky and non-plastic, few roots, pH 8.1, slight effervescences with dilute HCl, regular boundary. |

| | | |
|---|---|---|
| $B_1$ | 38-64 | Yellowish-brown (10 YR 5/4) when dry and dark yellowish-brown (10 YR 4/4) when moist, loamy sand, sub-angular blocky structure, single grain, loose and friable, no mottling, granular, fine roots but very few, pH 7.8, non-sticky and non-plastic, no effervescences with dilute HCl, regular boundary. |
| $B_2$ | 64-142 | Yellowish brown (10 YR 5/4) when dry and dark yellowish brown (10 YR 4/4) when moist, loamy sand, no mottlings, granular, loose and friable when dry, sub-angular blocky structure, absence of hard Kankar pan, non-sticky and non-plastic, few roots, pH 7.9, slight effervescences with dilute HCl, regular boundary. |

| | | | |
|---|---|---|---|
| Vegetation : | Pomegranate | - | Punica granatum |
| | Ber | - | Ziziphus jujuba |
| | Dhamasa | - | Tephrusia sarphonlea |
| | Aak | - | Calotropis procera |
| | Babul | - | Acacia arabica |
| | Khejri | - | Prosopis cineraria |
| | Neem | - | Azadirachta indica |
| | Doob | - | Cynondon dactylon |

## PROFILE NO. 3

| | |
|---|---|
| Location | - Agricultural Research Station, Durgapura (Jaipur) |
| Present land use | - Cultivated |
| Agro-climatic zone | - III-A |
| Climate | - Semi-arid |
| Slope | - 1 percent |
| Drainage | - Excessively drained |
| Order | - Entisol |
| Sub-order | - Psamment |
| Great group | - Ustipsamment |
| Soil series | - Chomu series (Tentative) |
| Thermo-regime | - Hyperthermic |

| Horizon | Depth (cm) | Description of the profile |
|---|---|---|
| $A_p$ | 0-12 | Light yellowish brown (10 YR 6/4) when dry and yellowish brown (10 YR 5/6) when moist, fine sand, single grain structure, loose and very friable, many fine and very fine fibrous roots, pH 8.3, clear smooth boundary, no effervescences with dilute HCl |
| $A_{12}$ | 12-25 | Light yellowish brown (10 YR 6/4) when dry and moist, loamy fine sand, weak very fine granular structure, very friable, very few 0.5 mm size soft, iron-manganese concretions, common fine and very fine fibrous roots, pH 8.1, gradual smooth boundary, no effervescences with dilute HCl. |

| | | |
|---|---|---|
| $B_{21}$ | 25-56 | Brown to dark brown (7.5 YR 4/4) when dry and moist respectively, loamy fine sand, weak fine sub-angular blocky and granular structure, friable, very few 0.5 iron-manganese concretions, common fine and very fine fibrous roots, many fine vertical tabular pores, pH 7.8, diffuse smooth boundary, slight effervescences with dilute HCl. |
| $B_{22}$ | 56-88 | Brown to dark brown (7.5 YR 4/4) when dry and moist respectively, loamy fine sand, very weak fine sub-angular blocky and granular structure, friable, few 0.5 mm size very soft iron-manganese concretions, few fine and very fine fibrous roots, many fine vertical tubelar pores, pH 7.7, diffused smooth boundary. Very slight effervescences with dilute HCl. |
| $B_3$ | 88-119 | Light brown (7.5 YR 6/4) when dry and moist loamy fine sand, single grain structure, few 0.5 mm size very soft iron-manganese concretions, few very fine fibrous roots, pH 7.7, no effervescences with dilute HCl. Diffuse smooth boundary. |
| $C_1$ | 119-172 | Strong brown (7.5 YR 5/6) when dry and moist, loamy fine sand, single grain structure, very friable, few very fine fibrous roots, pH 7.6, no effervescences with dilute HCl, gradual smooth boundary. |

Vegetation :

| | | |
|---|---|---|
| Neem | - | <u>Azadirachta indica</u> |
| Khejri | - | <u>Prosopis cineraria</u> |
| Babul | - | <u>Acacia arabica</u> |
| Ber | - | <u>Ziziphus jujuba</u> |
| Dhamasa | - | <u>Tephrusia sarphonlea</u> |
| Aak | - | <u>Calotropis procera</u> |
| Doob | - | <u>Cynondon dactylon</u> |

Wheat, barley and vegetables are grown under irrigation and pearlmillet, groundnut, sesamum etc. are grown under rainfed condition.

## PROFILE NO. 4

| | | |
|---|---|---|
| Location | - | Agricultural Research Sub-Station, Diggi (Tonk) |
| Present land use | - | Cultivated |
| Agro-climatic zone | - | III-A |
| Climate | - | Semi-arid |
| Slope | - | 1 percent |
| Drainage | - | Moderately slow |
| Order | - | Alfisol |
| Sub-order | - | Ustalf |
| Great group | - | Paleustalf |
| Soil series | - | Not known |
| Thermo-regime | - | Hyperthermic |

| Horizon | Depth (cm) | Description of the profile |
|---|---|---|
| $A_p$ | 0-24 | Dark brown (10 YR 4/3) when dry and moist, (10 YR 3/3), sandy loam, sub- |

| | | |
|---|---|---|
| | | angular blocky structure, compact/hard, friable when dry and plastic when moist and wet, slight effervescences with dilute HCl, neutral soil reaction (pH 7.5), small calcium concretions, few pores, irregular boundary. |
| $A_1$ | 24-53 | Dark brown (10 YR 4/3) when dry and very dark greyish-brown (10 YR 3/2) when moist, sandy loam, sub-angular blocky structure, compact/hard, friable when dry and plastic when moist and wet, slight effervescences with dilute HCl, soil reaction towards Saline (pH 7.6), small calcium concretions, many pores, irregular boundary. |
| $C_y$ | 53-81 | Yellowish brown (10 YR 5/8) when dry and dark yellowish brown (10 YR 5/4) when moist, sandy loam, sub-angular blocky structure, compact/hard, massive when dry and sticky when moist and wet, very high effervescences with dilute HCl, Saline soil reaction (pH 7.9), pores absent, irregular boundary. |
| $C_k$ | 81-152 | Greyish brown (10 YR 5/2) when dry and light brownish grey (10 YR 6/2) when moist, sub-angular blocky structure, compact/hard, massive when dry and sticky when moist and wet, vigourous effervescences with dilute HCl, pores absent, big calcium concretions, irregular boundary, pH 8.3 |

Vegetation :

| | | |
|---|---|---|
| Babul | - | *Acacia arabica* |
| Jhari | - | *Ziziphus nummularia* |
| Neem | - | *Azadirachta indica* |
| Kikar | - | *Acacia arabica* |
| Doob | - | *Cynondon cactylon* |

PROFILE NO. 5

| | | |
|---|---|---|
| Location | - | Roopangarh (Ajmer)<br>A Farmer's Field |
| Present land use | - | Cultivated |
| Agro-climatic zone | - | III-A |
| Climate | - | Semi-arid |
| Slope | - | 3 per cent |
| Drainage | - | Moderate |
| Order | - | Entisol |
| Sub-order | - | Psamment |
| Great group | - | Ustifluvents |
| Soil series | - | Not available |
| Thermo-regime | - | Hyperthermic |

| Horizon | Depth (cm) | Description of the profile |
|---|---|---|
| $A_p$ | 0-30 | Dark brown (10 YR 3/3) when dry and very dark greyish brown (10 YR 3/2) when moist, fine sand, sub-angular blocky structure, compact/hard, friable when dry, sticky when moist, and plastic when wet, slight effervescences with dilute HCl, Saline soil reaction, small murrum concretions, regular boundary. |

| | | |
|---|---|---|
| B | 30–60 | Yellowish brown (10 YR 5/6) when dry and dark brown (7.5 YR 4/4) when moist, fine sand, sub-angular blocky structure, loose, friable when dry and moist, sticky when moist and slightly plastic when wet, slight effervescences with dilute HCl, plenty pores, small calcium carbonate concretion Saline soil reaction, regular boundary. |
| C | 60–90 | Light grey (10 YR 7/1) when dry and pale brown (10 YR 6/3) when moist, fine sand loose, friable when dry and moist, sticky when wet, highly Saline soil reaction, layer of calcium carbonate concretions present, vigorous efferves-cences with dilute HCl, regular boundary. |

Vegetation :

| | | |
|---|---|---|
| Khejri | - | *Prosopis cineraria* |
| Kikar | - | *Acacia arabica* |
| Neem | - | *Azadirachta indica* |
| Doob | - | *Cynondon dactylon* |

## 4.2 Laboratory studies

Laboratory studies greatly help not only in providing suitable interpretation of field observations but also aid in predicting soil behaviour under different set of conditions. The findings of laboratory study are presented and discussed in the succeeding pages.

### 4.2.1 Physical characteristics of soils

Particle size distribution, apparent density, true density, total porosity, maximum water holding capacity and hydraulic conductivity are some of the commonly used physical properties of soils in investigations of soil characterization and in soil development studies. These parameters of the soils of the Agro-climatic zone III-A are presented below.

#### 4.2.1.1 Mechanical analysis

Mechanical analysis gives the percentage of sand, silt and clay fraction distribution in soils and points to their textural classification. The distribution of these fractions, in turn, govern the physico-chemical character of soils. The determination of soil texture is, therefore, a very important aspect for the adoption of management practices for the soils in question.

Profile No. 1

Textural class of the soils of this profile is loamy sand through out the profile and coarse skeleton are few in number. Data presented in Table 8 reveals that coarse sand content varies from 10.2 to 12.1 percent, Ap horizon contains maximum coarse sand while $B_1$ horizon contains minimum. Fine sand content varies from 71.9 to 73.0 percent. $A_2$ and $B_2$ horizons contains minimum fine sand, while $B_1$ horizon contains maximum. The silt content ranges between 8.3 to 10.0 percent and it was minimum in surface and sub-surface horizons

Table 8 : Mechanical analysis (Percent particle size distribution)

| Sr. No. | Horizon | Depth (cm) | Mechanical composition: Coarse sand(%) 2-0.2mm | Fine sand(%) 0.2-0.02 mm | Silt (%) 0.02-0.002mm | Clay (%) 0.002mm | Textural class |
|---|---|---|---|---|---|---|---|
| | | | **Profile No. 1 Jobner Well No. 10** | | | | |
| 1 | $A_p$ | 0-53 | 12.10 | 72.30 | 8.30 | 7.30 | Loamy sand |
| 2 | $A_1$ | 53-80 | 11.50 | 72.00 | 9.10 | 7.40 | Loamy sand |
| 3 | $A_2$ | 80-127 | 10.8 | 71.90 | 9.30 | 7.90 | Loamy sand |
| 4 | $B_1$ | 127-160 | 10.2 | 73.00 | 8.90 | 7.90 | Loamy sand |
| 5 | $B_2$ | 160-200 | 11.1 | 71.90 | 10.00 | 7.00 | Loamy sand |
| | | | **Profile No. 2 Asalpur Farm** | | | | |
| 6 | A | 0-38 | 18.50 | 64.00 | 7.00 | 6.75 | Loamy sand |
| 7 | $B_1$ | 38-64 | 18.60 | 63.30 | 10.30 | 7.80 | Loamy sand |
| 8 | $B_2$ | 64-142 | 15.40 | 66.40 | 10.90 | 7.30 | Loamy sand |
| | | | **Profile No. 3 A.R.S., Durgapura** | | | | |
| 9 | $A_p$ | 0-12 | 39.40 | 49.00 | 6.90 | 4.70 | Fine sand |
| 10 | $A_{12}$ | 12-25 | 35.70 | 51.20 | 5.60 | 7.40 | Loamy fine sand |
| 11 | $B_{21}$ | 25-56 | 32.40 | 54.70 | 5.70 | 7.20 | Loamy fine sand |
| 12 | $B_{22}$ | 56-88 | 33.00 | 53.60 | 5.40 | 7.90 | Loamy fine sand |
| 13 | $B_3$ | 88-119 | 33.40 | 53.60 | 5.20 | 7.80 | Loamy fine sand |
| 14 | $C_1$ | 119-170 | 34.10 | 52.70 | 6.10 | 7.10 | Loamy fine sand |
| | | | **Profile No. 4 A.R.S.S., Diggi** | | | | |
| 15 | $A_p$ | 0-24 | 3.20 | 67.60 | 14.40 | 14.80 | Sandy loam |
| 16 | $A_1$ | 24-53 | 3.53 | 62.93 | 17.83 | 15.70 | Sandy loam |
| 17 | $C_y$ | 53-81 | 3.03 | 62.33 | 16.40 | 18.23 | Sandy loam |
| 18 | $C_k$ | 81-152 | 5.87 | 65.10 | 18.73 | 10.23 | Sandy loam |
| | | | **Profile No. 5 Roopangarh, A Farmer's field** | | | | |
| 19 | $A_p$ | 0-30 | 6.40 | 76.50 | 8.80 | 8.30 | Fine sand |
| 20 | B | 30-60 | 5.30 | 73.60 | 11.30 | 9.80 | Fine sand |
| 21 | C | 60-90 | 4.30 | 80.20 | 8.03 | 7.50 | Fine sand |

($A_p$ and $B_1$), whereas it was found maximum in $B_2$ horizon, clay contributes 7.0 to 7.9 percent. $A_2$ horizon contains maximum clay while, $B_2$ horizon contains minimum. Higher concentration of clay in the horizons $A_2$ and $B_1$ shows illuviation in these horizons.

Profile No. 2

Textural class of the soil located at Asalpur farm is loamy sand throughout the profile. Coarse sand content varies from 15.4 to 18.6 percent $B_1$ horizon contains maximum coarse sand, while $B_2$ horizon contains minimum. Fine sand content ranges between 63.3 to 66.4 percent. In this profile the minimum fine sand content was found in $B_1$ horizon whereas maximum fine sand content was observed in case of $B_2$ horizon. Silt content in this profile varies from 7.0 to 10.9 percent. $A_p$ horizon contains minimum silt percent, while $B_2$ horizon shows maximum. Clay content in different horizons ranges from 6.75 to 7.8 percent. Maximum clay content is noticed in $B_1$ horizon and minimum in surface ($A_p$) horizon. A distinct clay accumulation is observed in $B_1$ horizon.

Profile No. 3

Textural class of the soils of this profile varies from fine sand to loamy fine sand. Coarse sand content varies from 32.4 to 39.4 percent. Data reveals that $A_p$ horizon contains maximum coarse sand whereas, $B_{21}$ horizon contains minimum. Fine sand content ranges from 49.0 to 54.7

percent. In this profile minimum fine sand content was found in Ap horizon. On the other hand, maximum fine sand content was observed in case of $B_{21}$ horizon. Silt content varies from 5.2 to 6.9 percent. $A_p$ horizon contains maximum silt percent, while $B_3$ horizon shows minimum. Clay content varies from 4.7 to 7.9 percent and data presented in Table 8 indicates that it was maximum in $B_{22}$ horizon and minimum in the upper most horizon ($A_p$) of the profile.

Profile No. 4

Textural class of the soils located at Agricultural Research Sub-Station, Diggi is sandy loam throughout the profile. Recently deposited alluvium of profile shows greater variation in coarse skeleton. Coarse sand content varies from 3.03 to 5.87 percent, Ck-horizon contains maximum amount of coarse sand (5.87 percent), whereas, Cy-horizon contains minimum. Fine sand content ranges between 62.33 to 67.60 percent. In this profile minimum fine sand content (62.33 percent) was found in $C_y$ horizon, while, maximum fine sand content was observed in case of $A_p$ horizon (67.60 percent). Silt content increases with depth in this profile and varies from 14.40 to 18.73 percent. Clay content also increases with depth upto $C_y$ horizon but in $C_k$ horizon it shows a decreasing trend and its content was minimum (10.30 percent). Clay contributes 10.30 to 18.23 percent. $C_y$ horizon contains maximum amount of clay, while, $C_k$ horizon contains minimum.

Profile No. 5

Texture of the soils of this profile is fine sand throughout the profile. Data presented in Table 8 reveals that coarse sand content decrease with the depth and it ranges between 4.3 to 6.4 percent. $A_p$ horizon contains maximum coarse sand while, C horizon contains minimum. Fine sand content does not show any specific pattern and varies from 73.6 to 80.2 percent. Silt content of this profile varies from 8.03 to 11.3 percent. B horizon contains maximum silt percent, whereas, C horizon shows minimum. Clay content varies from 7.5 to 9.8 percent. Maximum clay content is noticed in B horizon, whereas, C horizon contains minimum clay percentage.

4.2.1.2 <u>Bulk density</u>

In general apparent density (B.D.) increases with increase in amount of illuviated clay. Besides this the increase in bulk density with depth was apparently associated with the decrease in organic carbon, less aggregation, root penetration and the compaction caused by the weight of overlying mass. Secondary accumulation or orientation of clay in pore space has increased the bulk density of sub-surface B horizon in all profiles under study area.

Data presented in Table 9 indicates that the apparent density of soils of the profiles 1, 2, 3, 4 and 5 varies from 1.51 to 1.58, 1.54 to 1.56, 1.50 to 1.62, 1.32 to 1.39 and 1.42 to 1.49 gm/cc, respectively. An increasing trend of the bulk density with depth was observed in all the profiles except profile No.5. The bulk density values of surface

Table 9 : Physical constants.

| Sr. No. | Horizon | Depth (cm) | Apparent density (B.D.) gm/cc | True density (P.D.) gm/cc | Total porosity (%) | Water holding capacity (%) | Hydraulic conductivity (cm/hr) |
|---|---|---|---|---|---|---|---|
| | | | **Profile No. 1 Jobner College Well No.10** | | | | |
| 1 | $A_p$ | 0-53 | 1.51 | 2.60 | 41.92 | 27.11 | 6.72 |
| 2 | $A_1$ | 53-80 | 1.52 | 2.60 | 41.53 | 29.04 | 6.26 |
| 3 | $A_2$ | 80-127 | 1.53 | 2.61 | 41.37 | 29.86 | 5.19 |
| 4 | $B_1$ | 127-160 | 1.55 | 2.55 | 39.21 | 33.60 | 4.83 |
| 5 | $B_2$ | 160-200 | 1.58 | 2.51 | 37.05 | 31.99 | 4.00 |
| | | | **Profile No. 2 Asalpur Farm** | | | | |
| 6 | A | 0-38 | 1.54 | 2.60 | 40.76 | 26.68 | 5.44 |
| 7 | $B_1$ | 38-64 | 1.55 | 2.58 | 39.92 | 28.03 | 4.53 |
| 8 | $B_2$ | 64-142 | 1.56 | 2.55 | 38.82 | 28.88 | 3.71 |
| | | | **Profile No. 3 A.R.S. Durgapura** | | | | |
| 9 | $A_p$ | 0-12 | 1.50 | 2.71 | 44.64 | 26.96 | 7.03 |
| 10 | $A_{12}$ | 12-25 | 1.52 | 2.68 | 43.28 | 29.18 | 6.53 |
| 11 | $B_{21}$ | 25-56 | 1.54 | 2.63 | 41.44 | 29.84 | 5.57 |
| 12 | $B_{22}$ | 56-88 | 1.57 | 2.62 | 40.07 | 30.62 | 5.00 |
| 13 | $B_3$ | 88-119 | 1.60 | 2.60 | 38.46 | 33.98 | 4.85 |
| 14 | $C_1$ | 119-172 | 1.62 | 2.58 | 37.20 | 35.50 | 4.72 |
| | | | **Profile No. 4 A.R.S.S., Diggi** | | | | |
| 15 | $A_p$ | 0-24 | 1.32 | 2.70 | 51.11 | 35.03 | 1.92 |
| 16 | $A_1$ | 24-53 | 1.33 | 2.75 | 51.63 | 37.01 | 1.71 |
| 17 | $C_y$ | 53-81 | 1.35 | 2.82 | 52.60 | 39.82 | 1.48 |
| 18 | $C_k$ | 81-152 | 1.39 | 2.75 | 49.45 | 26.28 | 3.42 |
| | | | **Profile No. 5 Roopangarh, A Farmer's field** | | | | |
| 19 | $A_p$ | 0-30 | 1.45 | 2.73 | 46.88 | 33.06 | 4.68 |
| 20 | B | 30-60 | 1.42 | 2.71 | 47.60 | 33.31 | 4.58 |
| 21 | C | 60-90 | 1.49 | 2.69 | 44.61 | 31.27 | 7.02 |

horizons had comparatively been low because of presence of organic matter in the upper horizons. An increase in the value of apparent density with depth, though slight, showed that there had been elluviation of finer materials leaving behind heavy un-weathered materials.

Furthermore, the increase in bulk density in lower layers could be attributed to burden of overlying strata. These results are in conformity with those obtained by Vyas et al. (1974), Northrup and Boyle (1975) and Pathak and Patel (1980).

4.2.1.3 Particle density

Particle density of soils of the profiles no. 1,2,3,4 and 5 varies from 2.51 to 2.61, 2.55 to 2.60, 2.58 to 2.71, 2.70 to 2.82 and 2.69 to 2.73 gm/cc, respectively. Thus, all profiles shows more or less same values of true density including similar mineralogy. Particle density showed in general a decreasing trend with the depth of the profiles, except profile No.4, where it increases with depth upto 81 cm depth. Increase in true density with depth in this profile indicates that the content of minerals may increase in lower horizons.

4.2.1.4 Total porosity

Nature of packing and degree of compactness of soils determine total porosity. On compacting soils, total porosity decreases. Properties of the soil like water holding capacity and air capacity depend on porosity.

Data presented in Table 9 reveals that the porosity of soils of the profiles 1,2,3,4 and 5 ranges from 37.05 to 41.92, 38.82 to 40.76, 37.20 to 44.64, 49.45 to 52.60 and 44.61 to 47.60 percent, respectively. The results of the total porosity revealed that these vary between 37.05 to 52.12 percent. Relatively higher values of total porosity had been observed in surface horizons as compared with lower layers of the profiles. Porosity decreased with depth in pedon 1,2 and 3 and it varied from 37.05 to 44.64 percent. But slight increase in porosity had been observed in the profile No. 4 and 5 at the lower horizons.

The soils of this agro-climatic zone have low values of the porosity because of low content of the organic matter and clay. Porosity of the soils decreases with depth due to increase in compactness of the sub-surface soils.

#### 4.2.1.5 Maximum water holding capacity (%)

Maximum water holding capacity ranges from 27.11 to 33.60, 26.68 to 28.88, 29.96 to 35.50, 26.28 to 39.82 and 31.27 to 33.31 percent for profile No. 1,2,3,4 and 5 respectively and it increases with depth due to increase in finner fractions at lower depths.

#### 4.2.1.6 Hydraulic conductivity (cm/hr)

Hydraulic conductivity of profile No. 1,2,3,4 and 5 varies from 4.00 to 6.72, 3.71 to 5.44, 4.72 to 7.03, 1.48 to 3.42 and 4.58 to 7.02 cm/hr respectively.

Hydraulic conductivity showed a regular decreasing trend with depth of the profiles except lowest horizons of the profiles 4 and 5, where it was found to increase. Decrease in hydraulic conductivity with the depth was due to the compactness, structureless conditions, low porosity and high water holding capacity of the sub-soil horizons.

#### 4.2.1.7 Physico-chemical and chemical characteristics of soils

##### (A) pH

Soil reaction is one of the most important property of soils because it controls availability of nutrients, microbial activity and physical conditions of soils upto a great extent.

It is apparent from Table 10 that pH of 1:2 soil water suspension varies from 7.6 to 8.2, 7.8 to 8.1, 7.6 to 8.3, 7.5 to 8.3 and 7.6 to 7.9 in profile no. 1,2,3,4 and 5, respectively. Thus different horizons of all the profiles were normal in soil reaction. These profiles were also rich in soluble sodium which was responsible for higher pH. The pH values showed a definite trend of decrease with depth except profile no.4 in which an increasing trend is observed.

##### (B) Calcium carbonate

Free carbonates own their origin from parent material as well as product of weathering, with development of soil, carbonate tend to leach down. In arid and semi-arid climates such movement generally leads to the formation of calcic horizon as seen in case of profile no.4.

On the basis of results presented in Table 10 it appears that the amount of calcium carbonate varies from 0.11 to 0.91, 1.35 to 1.39, 2.20 to 51.32 and 0.54 to 4.78 percent in profile no. 1,2,4 and 5 respectively. Whereas, in profile no.3 it was found almost nil.

An increasing trend of $CaCO_3$ content was observed in all the profiles except profile no. 3 and 4. In profile no. 3 calcium carbonate content was found almost nil, while, no definite trend of $CaCO_3$ content was observed in profile no.4. Increase in the $CaCO_3$ content in the lower depths indicates that the leaching of the calcium from surface soils takes place to the sub-surface soils and it was accumulated at sub-surface soils in the form of calcium carbonate as secondary carbonates. Similar results were also observed for soils of arid and semi-arid regions by Sidhu *et al*. (1971).

4.2.2 Analysis of saturation extract

Electrical conductivity, water soluble cations and anions determined in the saturation extract of different soil profile samples and calculated values like SAR and SSP are presented in Table 10 and are discussed as follows.

4.2.2.1 Electrical conductivity

The electrical conductivity of soils is the measure of the concentration of soluble salts. Electrical conductivity of saturation extract of soils at 25°C varies from 1.17 to 1.50, 1.10 to 1.40, 0.98 to 1.39, 1.84 to 2.10 and 1.38 to 1.77 $dSm^{-1}$ in profile no. 1,2,3,4 and 5 respectively. The maximum electrical conductivity was noted in the surface horizons in 1,2,4 and 5 profiles, whereas in profile no.3, it was maximum in fifth horizon (88-119 cm depth). Profile no. 1,2,4 and 5 showed a definite decreasing trend in electrical conductivity with depth, whereas no definite trend was observed in profile no.3.

The higher electrical conductivity in surface horizons of the most of soil profiles was due to accumulation of soluble salts, as a result of high temperature during the most of the part of the year encouraging high evapo-transpiration, that leads to an accumulation of salts on the surface. Restricted internal drainage also lead to the accumulation of soluble salts in the profiles. Similar result were observed by Thorne and Thorne (1954), Sindhu *et al*., (1976) and Vyas *et al*. (1982).

#### 4.2.2.2 Soluble cations

Various cations like calcium, magnesium sodium and potassium are present in soils and excess of sodium plays an important role in influencing salinity and alkalinity in the soils, whereas, excess of calcium makes the soils calcareous affecting thereby the physico-chemical character of soils.

##### (A) Calcium + Magnesium

Calcium plus magnesium content varied from 2.20 to 3.30, 2.50 to 3.24, 1.25 to 2.25, 2.61 to 3.10

Table 10 : Calcium carbonate (%) and analysis of saturation extract of different soil profiles.

| Sr. No. | Horizon | Depth (cm) | pH | EC of saturation extract $dSm^{-1}$ at 25°C | $CaCO_3$ (%) | Water soluble cations meq/litre | | | SAR | SSP (%) | Water soluble anions meq/litre | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $Ca^{++}+Mg^{++}$ | $Na^+$ | $K^+$ | | | $CO_3^{--}$ | $HCO_3^{--}$ | $SO_4^{--}$ | $Cl^-$ |
| | | | | | Profile No. 1 Jobner Well No. 10 | | | | | | | | | |
| 1 | $A_p$ | 0-53 | 8.2 | 1.50 | 0.11 | 2.28 | 12.30 | 0.42 | 11.60 | 83.63 | 0.20 | 3.90 | 1.99 | 8.91 |
| 2 | $A_1$ | 53-80 | 8.1 | 1.41 | 0.18 | 2.40 | 11.50 | 0.23 | 10.55 | 81.56 | 0.27 | 3.79 | 2.20 | 7.88 |
| 3 | $A_2$ | 80-127 | 7.9 | 1.27 | 0.30 | 2.20 | 10.10 | 0.20 | 9.71 | 80.80 | 0.18 | 3.30 | 2.22 | 6.80 |
| 4 | $B_1$ | 127-160 | 7.8 | 1.22 | 0.26 | 3.27 | 8.95 | 0.18 | 6.66 | 72.17 | - | 3.10 | 2.51 | 6.78 |
| 5 | $B_2$ | 160-200 | 7.6 | 1.17 | 0.91 | 3.30 | 8.50 | 0.10 | 5.87 | 71.42 | - | 3.00 | 2.70 | 6.20 |
| | | | | | Profile No.2 Asalpur Farm | | | | | | | | | |
| 6 | A | 0-38 | 8.1 | 1.40 | 1.35 | 2.50 | 11.30 | 0.20 | 10.18 | 80.71 | - | 3.30 | 1.80 | 8.90 |
| 7 | $B_1$ | 38-64 | 7.9 | 1.22 | 1.38 | 3.10 | 9.10 | 0.15 | 7.33 | 73.68 | 0.11 | 3.01 | 1.90 | 7.45 |
| 8 | $B_2$ | 64-142 | 7.8 | 1.10 | 1.39 | 3.24 | 8.55 | 0.11 | 6.11 | 71.84 | 0.07 | 2.40 | 2.41 | 7.07 |
| | | | | | Profile No.3 A.R.S., Durgapura | | | | | | | | | |
| 9 | $A_p$ | 0-12 | 8.3 | 1.13 | Trace | 1.25 | 9.90 | 0.30 | 12.53 | 86.46 | Trace | 2.60 | 1.90 | 6.96 |
| 10 | $A_{12}$ | 12-25 | 8.1 | 1.06 | Trace | 1.26 | 9.30 | 0.12 | 11.77 | 87.57 | Trace | 2.01 | 1.40 | 7.25 |
| 11 | $B_{21}$ | 25-56 | 7.8 | 0.98 | - | 1.40 | 8.40 | 0.15 | 10.12 | 84.42 | - | 2.20 | 1.60 | 6.15 |
| 12 | $B_{22}$ | 56-88 | 7.7 | 1.13 | - | 2.00 | 9.00 | 0.11 | 9.00 | 81.08 | - | 2.36 | 1.90 | 6.86 |
| 13 | $B_3$ | 88-119 | 7.7 | 1.39 | - | 2.21 | 11.60 | 0.10 | 11.15 | 83.45 | - | 2.10 | 2.00 | 9.80 |
| 14 | $C_1$ | 119-172 | 7.6 | 1.29 | - | 2.25 | 10.60 | 0.09 | 10.01 | 81.91 | - | 2.00 | 2.10 | 8.81 |
| | | | | | Profile No.4 A.R.S.S., Diggi | | | | | | | | | |
| 15 | $A_p$ | 0-24 | 7.5 | 2.10 | 2.20 | 2.70 | 18.20 | 0.38 | 15.60 | 85.48 | 0.46 | 4.20 | 3.90 | 12.73 |
| 16 | $A_1$ | 24-53 | 7.6 | 1.99 | 0.55 | 2.61 | 17.00 | 0.35 | 14.91 | 85.21 | 0.82 | 4.29 | 3.60 | 11.24 |
| 17 | $C_y$ | 53-81 | 7.9 | 1.89 | 22.47 | 3.00 | 16.00 | 0.20 | 13.11 | 83.33 | 0.55 | 4.11 | 3.90 | 10.65 |
| 18 | $C_k$ | 81-152 | 8.3 | 1.84 | 51.32 | 3.10 | 15.40 | 0.18 | 12.41 | 82.44 | 0.40 | 4.00 | 4.61 | 9.66 |
| | | | | | Profile No.5 Roopangarh, A Farmer's field | | | | | | | | | |
| 19 | $A_p$ | 0-30 | 7.9 | 1.77 | 0.54 | 1.40 | 16.00 | 0.30 | 19.27 | 89.90 | 0.21 | 3.00 | 3.51 | 10.98 |
| 20 | B | 30-60 | 7.8 | 1.74 | 0.74 | 1.51 | 15.70 | 0.26 | 18.25 | 89.86 | 0.29 | 2.61 | 3.80 | 10.78 |
| 21 | C | 60-90 | 7.6 | 1.38 | 4.78 | 1.78 | 12.00 | 0.18 | 12.76 | 85.95 | 0.31 | 2.01 | 3.90 | 7.74 |

and 1.40 to 1.78 meq/litre in profile number one to five respectively. It showed a regular increasing trend with soil depth in profile no. 2,3 and 5, whereas, in profile no.1 and 4 calcium plus magnesium content showed an irregular trend of distribution with depth. The content of $Ca^{++}$ + $Mg^{++}$ was low because in the presence of bicarbonate ions and high pH values, the calcium plus magnesium gets precipitated and its content goes on decreasing.

(B) Sodium

A perusal of the data in Table 10 indicates that sodium had been the dominant cation whose distribution varies from 8.5 to 12.30, 8.55 to 11.30, 8.4 to 11.6, 15.4 to 18.20 and 12.0 to 16.0 meq/litre in the soil pedons no. 1,2,3,4 and 5 respectively. The content of soluble sodium showed a definite trend of decrease with depth in profiles no. 1,2,4 and 5. However, an irregular trend was observed in profile no.3, where soluble sodium content had been maximum in the fifth layer of the pedon. Similar results were reported by Singh and Sharma (1970).

(C) Potassium

Potassium content was 0.42, 0.20, 0.30, 0.38 and 0.30 meq/litre in the surface horizons of profile no. 1 to 5 respectively. Potassium content showed a decreasing order with the depth in all the soil profiles. The reason of its low content and its decreasing order with depth was due to fixation of soluble potassium with soil clays.

Thus, it may concluded that increasing accumulation of calcium and magnesium in lower strata and their subsequent precipitation reflects the depth of leaching in soils leaving behind a relatively higher concentration of soluble sodium and potassium in the surface soils. These findings are similar to those reported by Mishra (1980) and Vyas *et al.* (1973) has also observed the similar results, while working on the content of cations in soils of Jaipur district indicating a similar trend.

### 4.2.2.3 Sodium adsorption ratio and soluble sodium percentage

#### (A) Sodium adsorption ratio

Its variation in the surface horizons in profile no. 1 to 5 was 11.60, 10.18, 12.53, 15.60 and 19.27 respectively. An irregular trend was observed in profile no.3. But in soil profile no. 1,2,4 and 5 it showed a decreasing trend with depth. The sodium adsorption ratio depends upon the amount of soluble sodium percentage and calcium plus magnesium content of the soil.

#### (B) Soluble sodium percentage

Its content in surface horizons in soil profiles from served numbers 1 to 5 was 83.63, 80.71, 86.46, 85.48 and 89.90 percent respectively. Soluble sodium percentage showed a regular decreasing trend with depth in the profile no. 1,2,4 and 5 whereas it showed an irregular distribution with depth in pedon no. 3. The variation in the soluble sodium percentage was related to the amount of sodium content as well as total soluble cations and anions.

4.2.2.4 Soluble anions

The role of anions particularly that of carbonates and bicarbonates in determining the salinity hazard has been emphasized by several workers (Richards, 1954; Northcoke and Skene, 1972; Agarwal et al., 1979). The distribution of soluble anions in soils is presented in Table 10.

(A) Carbonate

Carbonate was totally absent in the soil profile no. 3. However, carbonate was present in very minute quantity in profile no. 1,2,4 and 5.

(B) Bicarbonate

The content of bicarbonate varied from 3.90, 3.30, 2.60, 4.20 and 3.00 meq/litre in the surface horizons of 1 to 5 soil profiles respectively. It showed an irregular trend of distribution with depth in profile no.3, whereas the bicarbonate distribution in pedons 1,2,4 and 5 was decreased with depth (except in second horizon of the profile no.4) and their amounts in these profiles ranged from 2.01 to 4.29 meq/litre.

(C) Sulphate

Its content varied in the surface horizons of the soil profiles (1 to 5) and it was found to be 1.99, 1.80, 1.90, 3.90 and 3.51 meq/litre respectively. Data presented in Table 10 reveals that soluble sulphate content increased with depth in the profile no. 1,2,3 and 5. However, an irregular distribution was noted in profile no.4 and this may be due to the poor drainage condition.

(D) Chloride

Amongst anions, chloride ions were dominant in all the pedons studied and in general it decreased with depth. Soluble chloride content varies from 6.20 to 8.91, 7.07 to 8.90, 6.15 to 9.80, 9.66 to 12.73 and 7.74 to 10.98 meq/litre in profiles 1,2,3,4 and 5 respectively. In profile no. 1,2,4 and 5, the chloride content was found to decrease with depth. But an irregular trend was observed in the profile no.3. Hence, the surface soils contain more chloride as compared to sub-surface soils. A dominance of chloride ions over other anions had also been reported by Longenecker and Lyerly (1959) and Bhargava and Sharma (1982).

From the results obtained it can be said that these soils are high in water soluble cations as well as anions, due to the compactness of the sub-horizons. Pre-dominating cations and anions were sodium, chloride and sulphate ions. Except profiles no.4 and 5, the carbonate was present in traces. In all the soil profiles the electrical conductivity was higher in the surface horizons due to the accumulation of soluble salts as a result of evaporation and prevalance of high temperature during the most of the part of the year. These findings are similar to those reported by Sindhu et al. (1976) and Vyas et al. (1982).

4.2.3 Cation exchange capacity and exchangeable cations

Cation exchange capacity is a function of soil colloidal complexes and organic colloids. The soils of the region under study are low in organic matter and, therefore, cation exchange capacity primarily depends on the amount of clay present and type of clay minerals.

Cation exchange capacity and various cations were determined and results are given in Table 11.

Profile No. 1

The cation exchange capacity in this pedon varied from 4.98 to 5.60 C. Mol $kg^{-1}$ of soil. Soils of this profile are normal having exchangeable sodium percentage between 5.80 to 12.14 percent. Dominating cations on exchange complex are calcium and magnesium. Exchangeable calcium dominated over most of the other exchangeable cations and it varied from 3.66 to 3.80 C.mol $kg^{-1}$ of soil and it showed an increasing trend with depth except fourth layer (127-160 cm). Exchangeable magnesium is the next dominant cation in the profile and its content ranged from 0.81 to 0.90 C.mol $kg^{-1}$ of soil. Similar to the exchangeable calcium it also showed an increasing trend with depth.

The exchangeable sodium lies in the range of 0.28 to 0.68 C.mol $kg^{-1}$ of soil. There has been slight variation in the distribution of exchangeable potassium which occupies the smallest portion of exchange complex. It ranged between 0.10 to 0.43 C. mol $kg^{-1}$ of soil. But unlike the exchangeable calcium and magnesium cations, its content decreased with the depth of the profile. Similar trend was also shown by exchangeable sodium throughout all the depths of the profile. The exchangeable sodium percentage varied from 5.80 to 12.14. A regular decreasing trend with respect to ESP in general

Table 11 : Exchangeable cations, CEC and ESP of various soil profile in agro-climatic zone III-A of Rajasthan

| Sr. No. | Hori-zon | Depth (cm) | Exchangeable cations C.mol $kg^{-1}$ ($P^{+}$) of soil | | | | C.E.C. C.mol $kg^{-1}$ of soil ($P^{+}$) | Exchangeable sodium percentage |
|---|---|---|---|---|---|---|---|---|
| | | | $Ca^{++}$ | $Mg^{++}$ | $Na^{+}$ | $K^{+}$ | | |
| | | | **Profile No. 1 Jobner Well No. 10** | | | | | |
| 1 | $A_p$ | 0-53 | 3.66 | 0.81 | 0.68 | 0.43 | 5.60 | 12.14 |
| 2 | $A_1$ | 53-80 | 3.74 | 0.84 | 0.57 | 0.25 | 5.40 | 10.55 |
| 3 | $A_2$ | 80-127 | 3.78 | 0.86 | 0.51 | 0.20 | 5.30 | 10.17 |
| 4 | $B_1$ | 127-160 | 3.71 | 0.89 | 0.32 | 0.16 | 5.01 | 6.27 |
| 5 | $B_2$ | 160-200 | 3.80 | 0.90 | 0.28 | 0.10 | 4.98 | 5.80 |
| | | | **Profile No. 2 Asalpur Farm** | | | | | |
| 6 | A | 0-38 | 3.76 | 0.92 | 0.57 | 0.15 | 5.40 | 11.17 |
| 7 | $B_1$ | 38-64 | 3.85 | 0.96 | 0.39 | 0.11 | 5.30 | 7.35 |
| 8 | $B_2$ | 64-142 | 3.64 | 0.97 | 0.21 | 0.11 | 4.92 | 4.37 |
| | | | **Profile No. 3 A.R.S., Durgapura** | | | | | |
| 9 | $A_p$ | 0-12 | 3.00 | 1.20 | 0.76 | 0.63 | 5.60 | 13.57 |
| 10 | $A_{12}$ | 12-25 | 3.10 | 1.22 | 0.72 | 0.46 | 5.50 | 13.09 |
| 11 | $B_{21}$ | 25-56 | 3.50 | 1.68 | 0.70 | 0.55 | 6.44 | 10.29 |
| 12 | $B_{22}$ | 56-88 | 2.96 | 1.79 | 0.55 | 0.32 | 5.63 | 9.61 |
| 13 | $B_3$ | 88-119 | 3.05 | 1.81 | 0.65 | 0.29 | 5.80 | 11.20 |
| 14 | $C_1$ | 119-172 | 3.09 | 1.82 | 0.60 | 0.15 | 5.65 | 10.90 |
| | | | **Profile No. 4 A.R.S.S., Diggi** | | | | | |
| 15 | $A_p$ | 0-24 | 3.47 | 2.50 | 1.43 | 1.60 | 9.05 | - |
| 16 | $A_1$ | 24-53 | 3.79 | 2.21 | 1.16 | 1.14 | 8.27 | - |
| 17 | $C_y$ | 53-81 | 3.82 | 2.01 | 0.99 | 1.01 | 7.83 | - |
| 18 | $C_k$ | 81-152 | 4.10 | 1.20 | 0.85 | 0.38 | 6.52 | - |
| | | | **Profile No. 5 Roopangarh, A Farmer's field** | | | | | |
| 19 | $A_p$ | 0-30 | 3.88 | 2.01 | 1.65 | 0.77 | 8.01 | - |
| 20 | B | 30-60 | 3.90 | 1.59 | 1.09 | 0.62 | 8.30 | - |
| 21 | C | 60-90 | 3.91 | 0.82 | 0.72 | 0.29 | 5.75 | - |

was observed with depth of the profile.

Profile No. 2

Cation exchange capacity of the soils of this profile varies from 4.92 to 5.40 C. mol $kg^{-1}$ of soil. Exchange complexes are dominated by calcium and magnesium. The exchangeable calcium content varied from 3.64 to 3.85 C. mol $kg^{-1}$ of soil and no definite trend was shown with depth. Likewise, exchangeable magnesium being the next dominant exchangeable cation and its content increased with the soil depth. But its distribution ranged from 0.92 to 0.97 C. mol $kg^{-1}$ of soil. The exchangeable sodium and potassium contents ranged from 0.21 to 0.57 and 0.11 to 0.15 C. mol $kg^{-1}$ of soil, respectively. Both exchangeable sodium and potassium showed a regular decreasing trend with depth.

Exchangeable sodium percentage varies from 4.37 to 11.17 percent and it decrease with depth of the profile.

Profile No. 3

Cation exchange capacity ranges from 5.5 to 6.44 C. mol $kg^{-1}$ of soil and it showed an irregular trend with depth. Exchangeable calcium cation is dominating cation over magnesium, sodium and potassium in the soils of the different horizons of this profile and its content ranged from 2.96 to 3.50 C. mol $kg^{-1}$ of soil. It increased upto the depth of 56 cm and then in the lower layers it shows no definite trend. The exchangeable magnesium content ranges between 1.20 to 1.82

C. mol $kg^{-1}$ of soil. It showed a increasing trend with depth. The exchangeable sodium and potassium contents ranged between 0.55 to 0.76 and 0.15 to 0.63 C. mol $kg^{-1}$ of soil respectively and both showed a decreasing trend with depth.

Profile No. 4

The cation exchange capacity in this pedon varied from 6.52 to 9.05 C. mol $kg^{-1}$ of soil. Calcium is predominating exchangeable cation over other exchangeable cations in the soils under study and it varied from 3.47 to 4.10 C. mol $kg^{-1}$ of soil. It showed an increasing trend with depth. Exchangeable magnesium is the next dominant cation in the soils of this profile and its content ranged from 1.20 to 2.50 C. mol $kg^{-1}$ of soil and showed a reverse trend when compared with content of the exchangeable calcium.

On the other hand, exchangeable sodium and potassium ranged between 0.85 to 1.43 and 0.38 to 1.60 C. mol $kg^{-1}$ of soil respectively and both showed a regular decreasing trend with depth.

Profile No. 5

Soils are developed on younger coastal and littoral alluvium and aeolian sand and cation exchange capacity of these soils ranges from 5.75 to 8.30 C. mol $kg^{-1}$ of soil.

Dominating cations on exchange complex are calcium and magnesium and their content varied from 3.88 to 3.91 and 0.82 to 2.01 c. mol $kg^{-1}$ of soil respectively. Exchangeable calcium content showed a regular increasing trend with depth of the profile, whereas, the exchangeable magnesium content showed a reverse trend. The exchangeable sodium lies in the range of 0.72 to 1.65 c. mol $kg^{-1}$ of soil. There has been slight variation in the distribution of exchangeable potassium which occupies the smallest portion, i.e., its content ranged between 0.29 to 0.77 c. mol $kg^{-1}$ of soil. Both exchangeable sodium and potassium showed similar increasing trend with depth of the profile.

In general soils under study are quite low in CEC and in most of the profiles it showed a decreasing trend with depth. This was due to low organic matter content and low finer fractions in these soils. The predominating exchangeable cations were Ca + Mg. While, exchangeable sodium and potassium were present in small quantities.

### 4.2.4 Fertility status of soils

In all twenty one soil samples were collected from the different sites of the area under study and these were analysed for organic carbon (as a measure of available nitrogen), available phosphorus and available potassium. Fertility classes were assigned according to standard of soil testing in India. Data on organic matter, available N, P and K are given in Table 12 and summarised below.

In all profiles organic carbon, available phosphorus and available potash ranges between 0.051 to 0.657 percent, 9.10 to 38.7 and 119.0 to 253.2 kg $ha^{-1}$ respectively.

4.2.4.1 Organic matter

The organic matter content of soil not only plays an important role in increasing CEC of soils but also contributes a great deal both directly and indirectly by influencing many physico-chemical properties of the soils. It is, thus, very important from soil fertility point of view.

The organic matter content of these soils had generally been very low and it varied from 0.051 to 0.657 percent. Its content regularly decreases with depth of the profiles. Diggi soil (Profile no.4) had the highest organic matter content among all the soils under study. The cause of low organic matter content in all these soils had been because of the absence of natural vegetation, low precipitation and prevailing high temperature leading to extremely high oxidising conditions. Results of the present investigation have been in confirmation with those reported by Dave (1974) and Joshi and Ghosinkar (1979).

4.2.4.2 Available nitrogen

A perusal of data in Table 12 revealed that available nitrogen varied from 108.8 to 134.5, 121.6 to 136.5, 113.0 to 131.2, 108 to 188 and 94.0 to 193.0 kg $ha^{-1}$

Table 12 : Fertility of soils and sub-soils, pH, organic matter, available nitrogen, available phosphorus and available potassium.

| Sr. No. | Horizon | Depth (cm) | pH (1:2) | Organic matter | | Available nitrogen | | Available phosphorus | | Available potassium | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Percent-age | Class | kg/ha | Class | kg/ha | Class | kg/ha | Class |
| | | | | | Profile No. 1 Jobner Well No. 10 | | | | | | |
| 1 | $A_p$ | 0-53 | 8.2 | 0.310 | Low | 134.5 | Low | 17.6 | Medium | 166.7 | Medium |
| 2 | $A_1$ | 53-80 | 8.1 | 0.293 | Low | 131.2 | Low | 18.1 | Medium | 165.1 | Medium |
| 3 | $A_2$ | 80-127 | 7.9 | 0.283 | Low | 125.5 | Low | 14.5 | Medium | 143.0 | Medium |
| 4 | $B_1$ | 127-160 | 7.8 | 0.195 | Low | 117.6 | Low | 11.2 | Low | 135.0 | Medium |
| 5 | $B_2$ | 160-200 | 7.6 | 0.189 | Low | 108.8 | Low | 9.10 | Low | 119.0 | Medium |
| | | | | | Profile No. 2 Asalpur Farm | | | | | | |
| 6 | A | 0-38 | 8.1 | 0.238 | Low | 136.5 | Low | 12.4 | Medium | 161.2 | Medium |
| 7 | $B_1$ | 38-64 | 7.9 | 0.233 | Low | 130.5 | Low | 12.4 | Medium | 152.75 | Medium |
| 8 | $B_2$ | 64-142 | 7.8 | 0.206 | Low | 121.6 | Low | 11.2 | Low | 132.5 | Medium |
| | | | | | Profile No. 3 A.R.S., Durgapura | | | | | | |
| 9 | $A_p$ | 0-12 | 8.3 | 0.310 | Low | 131.2 | Low | 35.7 | High | 170.0 | Medium |
| 10 | $A_{12}$ | 12-25 | 8.1 | 0.120 | Low | 129.7 | Low | 33.2 | High | 163.2 | Medium |
| 11 | $B_{21}$ | 25-56 | 7.7 | 0.103 | Low | 127.1 | Low | 29.6 | High | 144.3 | Medium |
| 12 | $B_{22}$ | 56-88 | 7.7 | 0.068 | Low | 119.0 | Low | 24.7 | Medium | 135.0 | Medium |
| 13 | $B_3$ | 88-119 | 7.7 | 0.068 | Low | 124.0 | Low | 19.8 | Medium | 129.0 | Medium |
| 14 | $C_1$ | 119-172 | 7.6 | 0.051 | Low | 113.0 | Low | 11.0 | Low | 121.0 | Medium |
| | | | | | Profile No.4 A.R.S.S., Diggi | | | | | | |
| 15 | $A_p$ | 0-24 | 7.5 | 0.657 | Low | 188.0 | Low | 38.7 | High | 253.2 | Medium |
| 16 | $A_1$ | 24-53 | 7.6 | 0.479 | Low | 176.0 | Low | 33.8 | High | 244.0 | Medium |
| 17 | $C_y$ | 53-81 | 7.9 | 0.360 | Low | 158.0 | Low | 25.0 | Medium | 209.3 | Medium |
| 18 | $C_k$ | 81-152 | 8.3 | 0.293 | Low | 108.0 | Low | 19.5 | Medium | 192.7 | Medium |
| | | | | | Profile No.5, Roopangarh (Ajmer) A Farmer's Field | | | | | | |
| 19 | $A_p$ | 0-30 | 7.9 | 0.603 | Low | 193.0 | Low | 22.0 | Medium | 234.0 | Medium |
| 20 | B | 30-60 | 7.8 | 0.379 | Low | 134.0 | Low | 18.0 | Medium | 211.0 | Medium |
| 21 | C | 60-90 | 7.6 | 0.103 | Low | 94.0 | Very low | 11.1 | Low | 187.0 | Medium |

in the individual pedon 1,2,3,4 and 5 respectively. However, available nitrogen content in surface horizons of profile no. 1 to 5 was 134.5, 136.5, 131.2, 188.0 and 193.0 kg $ha^{-1}$ respectively.

In all the profiles the soils of surface horizon contain maximum available nitrogen, while minimum nitrogen was present in the bottom layer of each profile. It showed a regular trend of decrease with depth in all the profiles under study. These soils are rated as low in available nitrogen content.

4.2.4.3 Available phosphorus

Available phosphorus content of the soils of surface horizons was 17.6, 12.44, 35.7, 38.7 and 22.0 kg $ha^{-1}$ in the profile no. 1,2,3,4 and 5 respectively. Available phosphorus content showed a decreasing trend with the depth of the profiles. Soils of profile no. 1,2 and 5 were found to be medium to low in available phosphorus content, but soils of profile 3 and 4 were high to medium in available phosphorus.

4.2.4.4 Available potassium

Most of the available potassium (more than 95 percent) is present in the crystal lattices of silicate minerals. The micas (Muscovite and biotite) and feldspar (Orthoclase and microcline etc.) are the major potash bearing minerals which on weathering slowly release potash to soil.

A perusal of data in Table 12 revealed that available potassium of the soils under study varied from 119.0 to 166.7, 132.5 to 161.2, 121.0 to 170.0, 192.7 to 253.2 and 187.0 to 234.0 kg $ha^{-1}$ in the individual pedon no. 1,2,3,4 and 5 respectively. Surface horizons of the soil profiles (1 to 5) the available potassium content were observed as 166.7, 161.2, 170.0, 253.2 and 234.0 kg $ha^{-1}$ respectively. Available potassium content decreases with the depth of the profile and was associated with the decrease in organic matter, available nitrogen and available phosphorus contents with the depth. Soils under study were found medium in available potassium.

Table 13 : Fertility status of the study area.

| Site | Available nitrogen | Available Phosphorus | Available Potassium |
|---|---|---|---|
| Jobner College, Agronomy farm | Low | Low to Medium | Medium |
| Asalpur Agriculture Farm | Low | Low to Medium | Medium |
| A.R.S., Durgapura(Jaipur) | Low | Medium to High | Medium |
| ARSS, Diggi (Malpura) | Low | Medium to High | Medium |
| Roopangarh, A Farmer's Field (Ajmer) | Low to very low | Medium | Medium |

From the foregoing results of the study area, it is evident that available nitrogen and organic matter content of most of the samples are low, whereas, available phosphorus content is medium to high (except sub-soils of the profile 1,2) and available potassium content is almost medium (Table 13). These results are in conformity with findings of Chandrasekharan et al. (1970), Gorantiwar et al. (1974), Singh and Sahani (1975) and Sanghi et al. (1976).

## Classification according to soil taxonomy, 1973

On the basis of the profile features, detailed field observations and laboratory determinations, soils of agro-climatic zone III-A of semi-arid eastern plain in Rajasthan have been classified according to soil taxonomy, 1973.

Extreme climatic conditions prevail in the area studied due to high temperatures during most part of the year. The annual rainfall of 550 mm is received during monsoon lasting from July to last week of September. The evaporation exceeds the rainfall thus causing the arid conditions. The soils are, thus, grouped under the order Entisol and Alfisol according to U.S.D.A. comprehensive taxonomical classification of 7th approximation and all the profiles were grouped under the category of normal soil according to the classification suggested by the U.S.D.A. Salinity Laboratory, based on soil characteristics like pH, EC of saturation extract and exchangeable sodium percentage (Table 14).

Profile No.1

EC of saturation extract was recorded 1.50 $dsm^{-1}$ at the surface. Lowest value of EC, 1.17 $dsm^{-1}$ is observed in fifth horizon (160-200 cm). pH ranges from 7.6 to 8.2 and increased with the increase of exchangeable sodium percentage in all horizons. ESP is less than 15 per cent and ranges between 5.87 to 12.14 per cent.

Diagnostic criteria

| | |
|---|---|
| Order - Entisol | Recently developed soil, little profile development, presence of ochric epipedon and no any diagnostic horizon. |
| Sub-order - Psamment | Psamment have textures of loamy fine sand or coarse and are well drained. |
| Great group - Ustipssamment | Ustipssamments with Ustic soil moisture regime. Soils are yellowish brown in colour, do not have natric horizon, duripan or plinthite. |
| Sub-group - Typic Ustipssamment | Soils having ustic moisture regime i.e. dry climate and usually hot in summer and an argillic horizon and are commonly found occurring around mineral grains and in packing voids. |

Profile No. 2

Soils are developed under very low water table conditions. The EC of saturation extract being 1.40 $dsm^{-1}$ at the surface and ranges from 1.10 $dSm^{-1}$ to 1.40 $dSm^{-1}$. ESP and pH ranges from 4.37 to 11.17 per cent and 7.8 to 8.1, respectively.

Diagnostic criteria

| | |
|---|---|
| Order - Entisol | Little or no evidence of profile development. Absence of marks of any major pedogenic process is the differentiating features of this group of soils. |
| Sub-order - Psamment | Soils of semi-arid regions having sand textures. |
| Great group - Ustipssamment | Ustic soil moisture regime. Soils are yellowish brown in colour, do not have natric horizon, duripan or plinthite. |
| Sub-group - Typic Ustipssamment | Soils having ustic moisture regime i.e. dry climate and usually hot in summer and an argillic horizon which comprises by accumulation of clay. |

Profile No. 3

Soils of this profile has pH less than 8.3. Electrical conductivity ranges from 0.98 to 1.39 $dsm^{-1}$ and exchangeable sodium percentage ranges from 9.61 per cent to 13.57 per cent.

Diagnostic criteria

| | |
|---|---|
| Order - Entisol | Recently developed soil, ochric epipedon present, no any other diagnostic horizon. |

Sub-order - Psamment — Psamment have textures of loamy fine sand or coarse and are excessively drained.

Great group - Ustipssamment — They are defined largely on the presence or absence of diagnostic horizons and the arrangement of these horizons. Ustipssamment with Ustolls. Ustic soil moisture regime present. Soils are light yellowish brown to dark-brown in colour and do not have natric horizon.

Sub - group - Typic Ustipssamment — Soils having ustic moisture regime i.e. dry climate and usually hot in summer and an argillic horizon are commonly found occurring around mineral grains and in packing voids.

Profile No. 4

The electrical conductivity decreases with depth and ranges from 1.84 $dsm^{-1}$ at the bottom to 2.10 $dsm^{-1}$ at the surface. pH ranges from 7.5 to 8.3.

Diagnostic criteria

Order - Alfisol — Presence of an ochric epipedon and argillic diagnostic horizon.

Table 14 : Nomenclature and classification of soils according to USDA salinity laboratory.

| S.No. | Depth (cm) | pH of soil paste | EC $dSm^{-1}$ | ESP | Class |
|---|---|---|---|---|---|
| | | Profile No. 1 Jobner College Well No.10 | | | |
| 1 | 0-53 | 8.2 | 1.50 | 12.14 | Normal |
| 2 | 53-80 | 8.1 | 1.41 | 10.55 | " |
| 3 | 80-127 | 7.9 | 1.27 | 10.17 | " |
| 4 | 127-160 | 7.8 | 1.22 | 6.27 | " |
| 5 | 160-200 | 7.6 | 1.17 | 5.80 | " |
| | | Profile No. 2 Asalpur Farm | | | |
| 6 | 0-38 | 8.1 | 1.40 | 11.17 | Normal |
| 7 | 38-64 | 7.9 | 1.22 | 7.35 | " |
| 8 | 64-142 | 7.8 | 1.10 | 4.37 | " |
| | | Profile No. 3 A.R.S., Durgapura | | | |
| 9 | 0-12 | 8.3 | 1.13 | 13.57 | Normal |
| 10 | 12-25 | 8.1 | 1.06 | 13.09 | " |
| 11 | 25-56 | 7.8 | 0.98 | 10.29 | " |
| 12 | 56-88 | 7.7 | 1.13 | 9.61 | " |
| 13 | 88-119 | 7.7 | 1.39 | 11.20 | " |
| 14 | 119-172 | 7.6 | 1.29 | 10.90 | " |
| | | Profile No. 4, A.R.S.S., Diggi | | | |
| 15 | 0-24 | 7.5 | 2.10 | - | - |
| 16 | 24-53 | 7.6 | 1.99 | - | - |
| 17 | 53-81 | 7.9 | 1.89 | - | - |
| 18 | 81-152 | 8.3 | 1.84 | - | - |
| | | Profile No. 5, Roopangarh "A Farmers Field" | | | |
| 19 | 0-30 | 7.9 | 1.77 | - | - |
| 20 | 30-60 | 7.8 | 1.74 | - | - |
| 21 | 60-90 | 7.6 | 1.38 | - | - |

| | |
|---|---|
| Sub-order - Ustalfs | Soils of semi-arid regions having an ustic moisture regime. |
| Great group - Paleustalf | Soils are yellowish brown to dark brown in colour. Presence of the calcic horizon. |
| Sub-group - Typic Paleustalf | No lithic contact within 50 cm. Presence of more than 20 cm thick argillic. |

Profile No. 5

Electrical conductivity of saturation extract being 1.77 $dSm^{-1}$ at the surface and lowest value of EC 1.38 $dSm^{-1}$ was observed in third horizon. pH ranges from 7.6 to 8.2.

Diagnostic criteria

| | |
|---|---|
| Order - Entisol | Recently developed soil. Presence of ochric epipedon and no any other diagnostic horizon. |
| Sub-order - Psamments | Soils of semi-arid regions having sand textures. Psamment have texture of loamy fine sand. |
| Great group - Ustifluvents | Soils having ustic moisture regime i.e. dry climate and usually hot in summer. |
| Sub-group - Typic Ustifluvents | Hyper-thermic temperature regime. |

4.4 Correlation between various properties of soils

Association between the few properties of soil have been studied with the help of correlation coefficient. These correlation coefficients indicate the extent to which the properties of soil in various horizons of the profile are related with the other properties of soils (Table 15).

Correlation coefficients were worked out between the following soil properties :

pH and electrical conductivity, exchangeable sodium percentage and hydraulic conductivity, exchangeable sodium percentage and total porosity, electrical conductivity and hydraulic conductivity, electrical conductivity and exchangeable sodium percentage and sodium adsorption ratio and exchangeable sodium percentage. From the data presented in Table 15 it is evident that the pH of the soils has shown a negative non-significant correlation with electrical conductivity of soil. In all the profiles the correlation is negative and non-significant at 1 percent level of significance. The graphical representation of the correlation between pH and EC have been presented in Figure 2.

Similar to the pH and electrical conductivity of the soils the exchangeable sodium percentage and hydraulic conductivity also have a negative and non-significant correlation in all the profiles. These results are confirmity with results obtained by Dixit and Lal (1972) and Lole et al. (1970). But exchangeable sodium percentage and total porosity of the soils have positive and significant correlations with

Table 15 : Correlation and linear regression equation between various properties of soil.

| Soil properties | Coefficient of correlation | Regression equations between properties of soil | Calculated 'b' values |
|---|---|---|---|
| 1. pH and EC | -0.17 | $\hat{Y} = 7.98 - 0.087\,X$ | - 0.087 |
| 2. ESP and HC | -0.063 | $\hat{Y} = 5.02 - 0.026\,X$ | - 0.026 |
| 3. ESP and total porosity | 0.722** | $\hat{Y} = 33.39 + 0.850\,X$ | + 0.850 |
| 4. EC and ESP | 0.653** | $\hat{Y} = 0.60 + 7.76\,X$ | + 7.76 |
| 5. SAR and ESP | 0.788** | $\hat{Y} = 3.10 + 0.713\,X$ | + 0.713 |
| 6. EC and HC | -0.694** | $\hat{Y} = 9.52 - 3.41\,X$ | - 3.41 |

19 degree of freedom.

* Significant at 5 percent level
** Significant at 1 percent level

FIG – 2. CORRELATION BETWEEN pH AND ELECTRICAL CONDUCTIVITY.

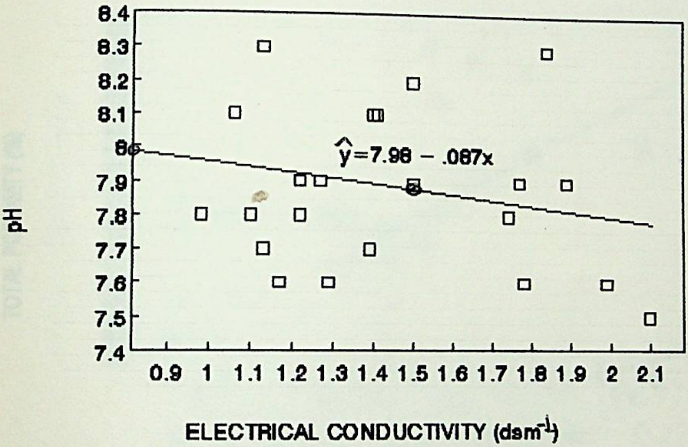



FIG – 3. CORRELATION BETWEEN EXCHANGEABLE SODIUM PERCENTAGE AND HYDRAULIC CONDUCTIVITY.

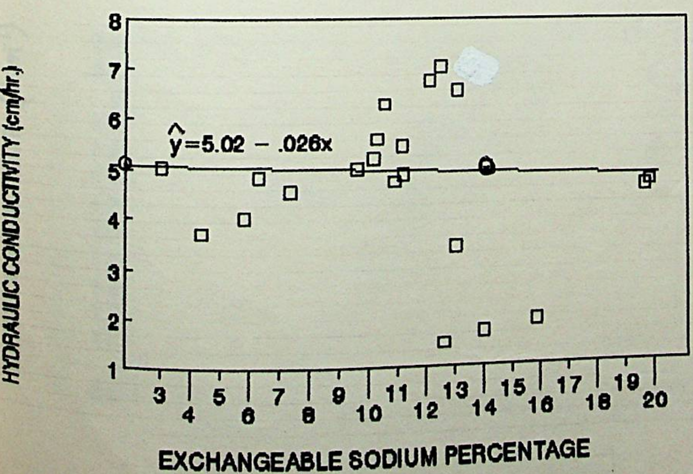


FIG – 4. CORRELATION BETWEEN EXCHANGEABLE SODIUM PERCENTAGE AND TOTAL POROSITY.

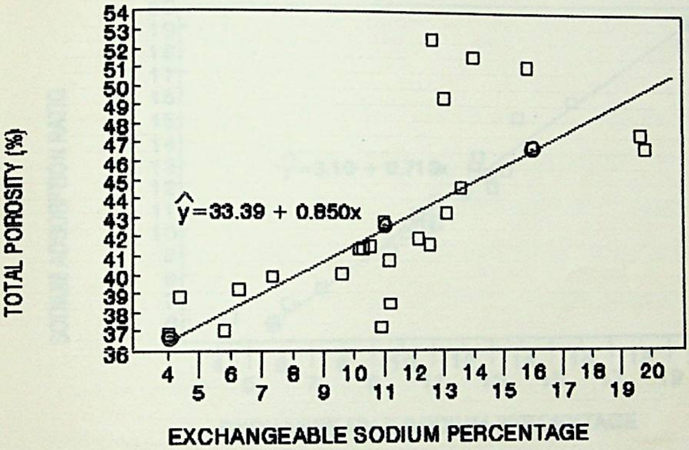



FIG – 5. CORRELATION BETWEEN ELECTRICAL CONDUCTIVITY AND EXCHANGEABLE SODIUM PERCENTAGE.

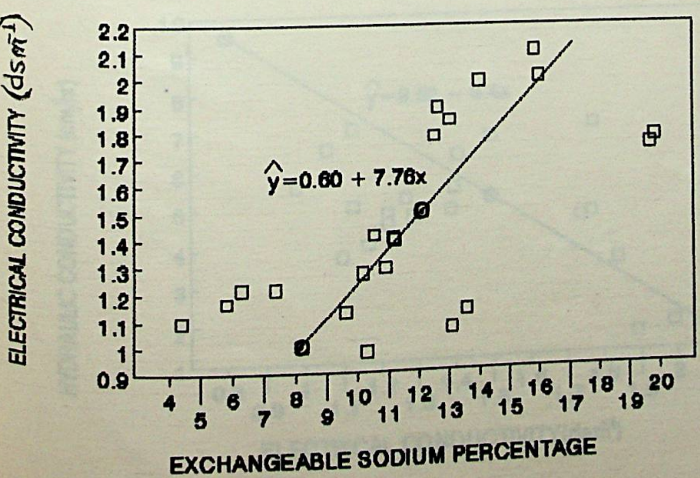


FIG – 6. CORRELATION BETWEEN SODIUM ADSORPTION RATIO AND EXCHANGEABLE SODIUM PERCENTAGE.

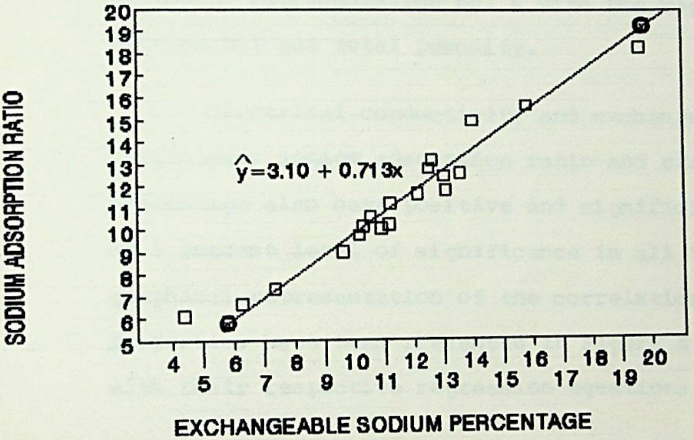
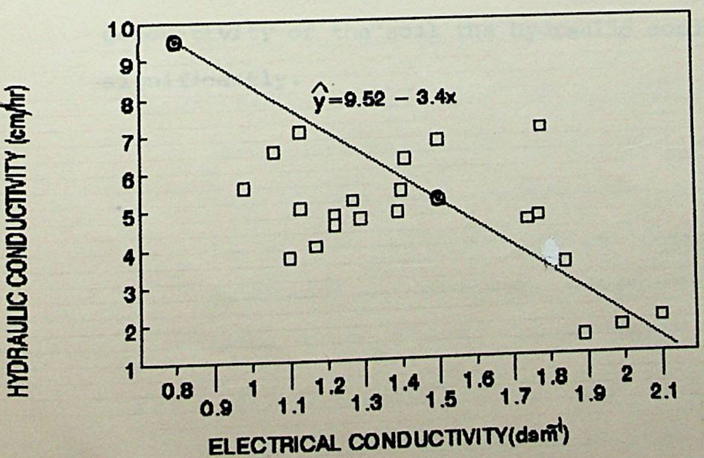



FIG – 7. CORRELATION BETWEEN ELECTRICAL CONDUCTIVITY AND HYDRAULIC CONDUCTIVITY.



each other. It shows that as the exchangeable sodium percentage decreases the total porosity also decrease. This positive significant correlation is shown in graphical representation no. 4 with the regression equation between ESP and total porosity.

Electrical conductivity and exchangeable sodium percentage, sodium adsorption ratio and exchangeable sodium percentage also have positive and significant correlations at 1 percent level of significance in all the soils. The graphical representation of the correlation between these properties have been presented in Figure 5 and 6 respectively with their respective regression equations.

The data presented in Table15 shows that the electrical conductivity and hydraulic conductivity have a negative and significant correlations at 1 percent level of significance. It indicates that with increase in electrical conductivity of the soil the hydraulic conductivity decreases significantly.

## SUMMARY AND CONCLUSION

Twenty-one soil samples from five profiles representing agro-climatic zone III-A of Rajasthan were collected and analysed for textural separates, physico-chemical properties, water soluble salts, cation exchange capacity and exchangeable cations. In addition, morphological studies of these soils were done to ascertain cause of development of these soils. The physical and chemical studies of soils were carried out to evaluate fertility status and to classify soils according to soil taxonomy, 1973.

The important findings of the present study are summarized as follows :

1. soils of profile no.1 are yellowish brown, loamy sand, very deep and well drained. Organic matter varies from 0.189 to 0.310 per cent and available phosphorus and potassium varies from 9.10 to 18.1 and 119.0 to 166.7 kg/ha, respectively.

2. soils of profile no.2 are yellowish brown to dark yellowish brown, loamy sand, non-calcareous, non-sodic, deep to very deep and moderately drained. Organic matter varies from 0.206 to 0.238 per cent and available phosphorus and potassium varies from 11.2 to 12.4 and 132.0 to 161.2 kg/ha, respectively.

3. soils of profile no.3 are light yellowish brown to dark brown, loamy fine sand, deep to very deep and excessivel[y] drained. Organic matter content varies from 0.051 to 0.3[...] per cent and available phosphorus and available potassiu[m]

ranges from 11.0 to 35.7 and 121.0 to 170.0 kg/ha, respectively.

4. Soils of profile no.4 are yellowish brown to dark brown, sandy loam and moderately drained. Organic matter content ranges between 0.293 to 0.657 per cent, available phosphorus and available potassium varies from 19.5 to 38.5 and 192.7 to 253.2 kg/ha, respectively.

5. Soils of profile no.5 are dark brown, fine sand and moderately drained. Organic matter content ranges between 0.103 to 0.603 per cent. Available phosphorus and available potassium ranges from 11.1 to 22.0 and 187.0 to 234.0 kg/ha, respectively.

Available nitrogen of most of the soil samples are low, whereas, available phosphorus is medium to high and available potassium is medium. Profile-wise fertility status is presented below :

| Profile No. | Fertility Status | | |
|---|---|---|---|
| | N | P | K |
| 1 | Low | Medium | Medium |
| 2 | Low | Low to medium | Medium |
| 3 | Low | Medium to high | Medium |
| 4 | Low | Medium to high | Medium |
| 5 | Very low | Medium | Medium |

All the soils under study appear to be fairly good in physical conditions as the texture of these soils varied from sandy to loamy sand. The organic matter content of these soils is low.

Apparent density and water holding capacity of these soils follow a trend of increase with depth, whereas, opposite trend is noticed in case of total porosity and true densities of these soils.

Calcium carbonate content of these soils show a trend of increase with depth in most of the profiles. These soils are normal.

Soils under study are rich in water soluble ions. The dominating anions are chloride, followed by bicarbonate and sulphate. In some of the profiles or horizons the carbonate content is totally absent. Water soluble sodium is the predominant cation. The next dominant cations are calcium plus magnesium followed by potassium which is present in decreasing order with depth.

These soils are low in cation exchange capacity, because of their light textural character having low colloidal content. Among the exchangeable cations, calcium predominates over magnesium, sodium and potassium. A definite decreasing trend is noticed regarding cation exchange capacity with depth of the profiles.

On the basis of field observations and laboratory determinations, soils have been classified according to soil taxonomy, 1973 into following great groups.

| Profile No. | Order | Sub-order | Great group | Sub-group |
|---|---|---|---|---|
| Profile no. 1 (Jobner College Farm) | Entisol | Psamment | Ustipssamment | Typic Ustipssamment |
| Profile no. 2 (Asalpur Farm) | Entisol | Psamment | Ustipssamment | Typic Ustipssamment |
| Profile no. 3 (A.R.S., Durgapura) | Entisol | Psamment | Ustipssamment | Typic Ustipssamment |
| Profile no. 4 (A.R.S.S., Diggi) | Alfisol | Ustalfs | Paleustalf | Typic Paleustalf |
| Profile no. 5 (Roopangarh, Ajmer) | Entisol | Psamment | Ustifluvents | Typic Ustifluvents |

High temperatures prevail during most part of the year and evaporation exceeds the rainfall in the area of study. The soils are grouped under order "Entisol" and "Alfisol" according to soil taxonomy, 1973.

<u>Correlation between soil properties</u>

Significant correlation coefficients were worked out between the following properties of soil :

1. Exchangeable sodium percentage and total porosity of the soil have positive and significant correlations with each other.
2. The electrical conductivity has a positive significant correlation with exchangeable sodium percentage.
3. Sodium adsorption ratio and exchangeable sodium percentage have a positive significant correlation.

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