

**STUDIES ON SALT AFFECTED SOILS OF
UPPER KRISHNA PROJECT COMMAND AREA**

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JULY, 1996

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**STUDIES ON SALT AFFECTED SOILS OF
UPPER KRISHNA PROJECT COMMAND AREA**

Thesis Submitted to the
University of Agricultural Sciences, Dharwad
in partial fulfilment of the requirement for the
Degree of

Master of Science (Agriculture)
IN
SOIL SCIENCE

BY

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CERTIFICATE

This is to certify that the thesis entitled "STUDIES ON SALT AFFECTED SOILS OF UPPER KRISHNA PROJECT COMMAND AREA" submitted by Mr. ANILKUMAR N. YERESHEEMI, for the degree of MASTER OF SCIENCE (Agriculture) in Soil Science and Agricultural Chemistry of the UNIVERSITY OF AGRICULTURAL SCIENCES, DHARWAD, is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis of award of any degree, diploma, associateship, fellowship or other similar titles.

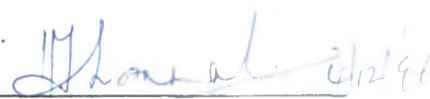
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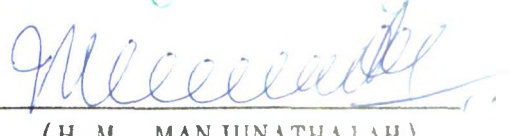
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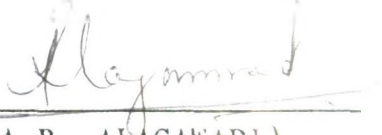
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DEDICATED TO
MY BELOVED PARENTS,
BROTHER & SISTERS

ACKNOWLEDGEMENT

I do not think one can effectively put one's heartfelt emotions in to words. It becomes all the more difficult for a person like me who is not endowed with this art. Whatever, I write here can only be a deceptive reflection of the tumult of feelings that is in my heart at this moment. When I write this, I am afraid, if these words made only mode and no substance. As a formal as it is essential I thank all those gentlemen who were directly or indirectly concerned with my studies for what all it were worth.

At the very out-set I express my heartfelt gratitude and reverence to Dr. H.T.CHANNAL, Associate Professor, Department of Soil Science, University of Agricultural Sciences, Dharwad, the esteemed chairman of my Advisory committee for his excellent guidance, constant encouragement, keen interest and everlasting patience throughout the course of this investigation.

As the movie runs, I greatly acknowledge to the other benevolent faces of my Advisory Committee members. Dr. SATHYANARAYANA, Professor and Head, Department of Soil Science, Dr. H.M.MANJUNATHAIAH, Professor, Department of Soil Science and Dr. A.R. ALAGAWADI, Associate Professor, Department of Soil Microbiology, University of Agricultural Sciences, Dharwad for their sound and fruitful advises and constructive criticism.

I am very much grateful to Dr. V.S.DODDAMANI, Dr. BASAVARAJ, Dr. P.L. PATIL, Mr. N.S.HEBSUR, Mr. B.HIREKURUBAR and Mr. M. PATAGUNDI, who have taken a lot of trouble in carrying out my research work.

My untold sense of gratitude and profound indebtedness to my beloved parents and family members without whose blessings and encouragement, I would not have grown to this level.

There is no excuse if I don't trouble my dearest friends, Sudhir, Gaddi, Viru, H.S, Raju, Siddu, Babu, William, Prabhu, Haller and Many others.

Finally I thank Mr. Anand and Nagaraj of Soft-tech computers for their neat and timely typing.

DHARWAD

July, 1996.


(ANILKUMAR N. VERESHEEMI)

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ABBREVIATIONS

BD	-	Bulk density
CEC	-	Cation exchange capacity
CSSRI	-	Central soil salinity research institute
Db	-	Total bulk density
Dp	-	Total particle density
DTPA	-	Diethylene triamine penta - acetic acid
EC	-	Electrical conductivity
ECe	-	Electrolyte conductivity of saturation
EM	-	Electromagnetic
ESP	-	Exchangeable sodium percentage
HC	-	Hydraulic conductivity
Ks	-	Saturated hydraulic conductivity
Mhos	-	Electrical conductance
MWHC	-	Maximum water holding capacity
Ohms	-	Electrical resistance
PD	-	Particle density
pH	-	Soil reaction
pHs	-	pH of saturated soil paste
SAR	-	Sodium adsorption ratio
St	-	Total porosity
TDR	-	Time -domain reflectometry
U.K.P	-	Upper Krishna project
U.S.S.L	-	United states salinity laboratory
VE	-	Volume expansion

INTRODUCTION

I . INTRODUCTION

Precisely at a time when population growth and rising expectations have begun to demand enormous increases in food production, the process of soil degradation has accelerated. The magnitude of the problems arising out of soil degradation can be realised from a rather astonishing fact that the world, as a whole, is losing at least ten hectare of arable land every minute, five because of soil erosion, three from soil salinization, one from soil degradation processes and one from non-agricultural uses (Buringh, 1979).

As the soil is subject to degradation, the cost of reclaiming it becomes higher, rising sharply until the threshold is passed beyond which reclamation is no longer feasible. So to say, the problem is of overwhelming emergency. Keeping in view the seriousness of the problem and the future food needs of increasing population, efforts of all the concerned need to be directed towards improving the level of management of soils already under cultivation and towards bringing under plough the potentially arable lands which are presently uncultivated. But salinity has been a major impediment in achieving increased crop yields by either of the above approaches.

Although accumulation of excess salts in the rootzone, resulting in a partial or complete loss of soil productivity, is a worldwide phenomenon, the problems of soil salinity and/or sodicity are most widespread in arid and

semi-arid regions of the world. And though in these areas the salt affected soils and the problems associated with them are not new, their magnitude and intensity have been increasing rapidly due to large scale efforts to bring additional areas under irrigation. The problems have been made worse by development of irrigation systems without adequate provision of drainage and are being aggravated by poor water management practices and non scientific reclamation procedures.

Unfortunately, the most serious salinity problems are being faced in the irrigated arid and semi-arid parts of the world and it is in these very regions that the essentiality of irrigation is next to none in bringing about increased agricultural production, to satisfy the food needs of the burgeoning global population.

According to Szabolcs (1989), an area of around 956 million hectares is estimated to suffer from the problem of salinity at the global level. In India also the problem is of no lesser dimension, with at least seven million hectares of land estimated to be covered by salt-affected soils, though figures as high as 26.1 million hectares have also been quoted (Singh, 1989).

The salt-affected soils distinguish themselves from their normal counterparts in various aspects, regardless of the region where they occur. Although not much affected with respect to their physical properties, saline soils contain sufficient neutral soluble salts to adversely influence the

growth of most crop plants. On the other hand, the chief characteristic of sodic soils from the agricultural standpoint is that they contain sufficient exchangeable sodium, which not only has an adverse effect on soil physical properties but also leads to imbalances in nutritional characteristics of the soils and consequently significant reduction in crop growth and yield.

This apart, salt-affected soils also differ considerably in distribution and availability of both major and minor nutrient elements. This is primarily on account of their low fertility status, salt-fertilizer interaction and due to physiological changes within crop plants in saline and/or sodic environment as compared to normal soils.

Eventhough the problems arising out of salinity and/or sodicity are not grave in Karnataka, nonetheless, the situation does not provide for complacency either. The problem is of particular concern in the Vertisols (black soils) occurring in various project areas. In India, Vertisols occupy about 7.3 million hectares and Karnataka accounts 31 per cent of it. Despite their inherent constraints, these soils make a substantial contribution to the state economy. However, of late, accumulation of excess salts in these soils, owing to excessive and unscrupulous use of canal water for irrigation, has been a great obstacle in realization of their full potential productivity. Of the 5.8 million hectares of area occupied by Vertisols in Karnataka, nearly 2.2 lakh

hectare area is salt-affected and the area is expected to rise further in future with extension of irrigation to more area.

Upper Krishna Project (U.K.P) Command Area, where black soils predominate (77 per cent), was boon to the farming community of northern Karnataka. But after the introduction of irrigation, 27 thousand hectare lands have become salt affected (Anonymous, 1993b).

The general characteristics and basic principles involved in the identification, reclamation and management of salt-affected soils are the same throughout the world. However, differences from place to place in soil characteristics, climate, water availability and others lead to differences in method, extent and rapidity of reclamation. The proper identification of nature and degree of soil salinity or sodicity and subsequent use of correct reclamation methods is the key to improve the productivity of these salt-affected soils.

Therefore the present investigation was carried out in some important soil series of Upper Krishna Project Command, with the following objectives :

1. To study physico - chemical properties of the soils and classify them into different categories, namely, saline, saline-sodic and sodic.
2. To determine available nutrient status of the soils and
3. To study the influence of sodicity, as measured by exchangeable sodium percentage (ESP), on some soil physical properties.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Salt-affected soils usually occur in association with their normal counterparts, but distinguish themselves in having higher concentration of electrolytes and poor to extremely poor fertility status, resulting in restricted availability and uptake of nutrients by plants (Szabolcs, 1989). An extensive research work has been carried out in India and abroad on characteristics and properties of salt-affected soils, with the end uses of these efforts are made use in classification, reclamation, engineering projects of all kinds and, some times, evaluation.

The buildup of salt content in a soil, which is generally the case in any salt - affected soil, may influence crop production in several ways through changes in the proportion of exchangeable and water soluble cations, soil reactions, physical properties of the soil and osmotic and specific ion toxicity effects. These changes have a great bearing on the activity of plant roots and soil microbes. Diagnosis and classification of salt - affected soils is generally based on pH, electrolyte conductivity (EC) and exchangeable sodium percentage (ESP). In addition, studying important soil physical properties such as porosity, bulk density (BD), maximum water holding capacity (MWHC) etc. is of considerable use in making such soils more productive.

Review of literature pertaining to the above said aspects of investigation have been presented briefly in this chapter under the following headings:

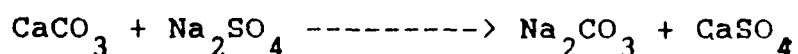
1. Genesis of salt- affected soils.
2. Characterization and classification of salt affected soils.
3. Physical properties of salt - affected soils and
4. Nutritional status of salt - affected soils.

1. Salt - affected soils: their origin and classification .

Various factors, such as geological factors, climatic conditions, hydrological processes and irrigation water quality, may act either independently or in combination, in formation of salt - affected soils.

2.1.1 Geological factors

The views regarding the primary sources of salts in salt - affected soils, seem to have undergone several changes over the years. The process of weathering , regardless of where it occurs, was indicated as the primary source by Hilgard (1906), who concluded that the alkali soils owed their properties to the formation of Na_2CO_3 probably formed by the reaction:



Kelley (1951), on the other hand, considered secondary deposits, such as shale , sandstone, glacial, wind-borne materials, and unconsolidated alluvium of various glacial ages, as the sources of salts.

Contrary to the opinion of Hilgard (1906), Na_2CO_3 formed as a result of release of sodium (Na^+) through base

exchange, was elucidated to be the cause of formation of alkali soils by Thomas (1977). In an investigation, directed to understanding the reactions responsible for high pH of soil with Na- saturated system, Cruz - Romero and Coleman (1975) observed that at lower concentration of soluble electrolytes and at lower pressure of carbon dioxide, formation of Na_2CO_3 was evidently rapid and was responsible for high pH of the soils. Later Gupta *et al.* (1984), while studying the effect of CaCO_3 and organic matter in soil alkalization, observed that in the presence of former, the rate of sodification increased, while the latter , when present in adequate quantities, was found to act in an opposite way.

In another study, undertaken to compare the relative effects of various factors in formation of sodic soils, Rajkumar *et al.* (1994) observed that relief and climate were not the major factors in formation of sodic soils. While investigating the occurrence of sodic soils at different locations and climate in the Satluj-Yamuna Divide, they found sodic soils to occur over a large area, with annual rainfall varying from less than 360 mm to more than 1100 mm. This observation, along with the occurrence of sodic conditions below a normal surface soil in pedons with lithological discontinuity, revealed that the parent material was the primary factor involved in origin of sodic soils.

1.2 Climatic Factors

As indicated earlier, nature of parent material plays a decisive role in formation of salt affected soils. However, this is not to underscore the importance of climate. In arid and semi-arid parts of the globe, wherein annual precipitation is well below the evaporation, the leaching of the products of weathering out of the profile is limited and therefore leads to accumulation of salts within the soil body, with the result that the saline soils occur mostly in these regions of the world (U.S.S.L.Staff, 1954).

Among the climatic factors, rainfall has been found to have a greater effect than the annual temperature in determining the soil salinity (Sen, 1958 ; Bhargava et al, 1980). These authors, while investigating the distribution of salt - affected soils in Haryana state, noticed that occurrence of salty soils was intimately related to the annual rainfall. In regions where the annual rainfall exceeded 900 mm, the soils were free of salt problems, while in areas which received 550-900mm of rainfall annually, the problem of sodicity was evident. But in those areas where rainfall is very low (less than 550mm/year) saline soils occurred with chlorides and sulphates as the main salts.

On the contrary, Raj Kumar et al, (1994) were of the opinion that the climate has virtually little relationship with the occurrence of sodic soils. In a study of sodic soils of Satluj-Yamuna Divide, they analyzed the water from two

plains, namely piedmont plains and alluvial plains. The quality of the water in the former was quite normal, while the waters from the latter plains were found to be saline to very saline. This sudden increase in the salt content of water, according to the authors, cannot be attributed to the climate differences in the soils of two plains, as temperature in both the transects is hyperthermic and soil moisture regime, ustic.

2.1.3 Hydrological factors

A high water table, at least temporarily, and evaporation were considered absolutely essential by Kelley (1951), for the salts to accumulate in a soil. In an attempt to investigate the effect of water table depth on soil salinization, Bandopadhyaya (1973) observed that the electrical conductivity [EC] was high near watertable and decreased upwards as the salts moved towards the rooting zone, with the highest EC values being associated with surface soil. In addition to high water table, seepage of water from uplands or unlined irrigation canals and consequent waterlogging, may also cause development of soil salinity (Katti and Rao, 1979).

2.1.4 Quality of irrigation waters

In order to minimize vagaries of arid weather, bring more land under irrigation , and produce and stabilize greater yields per unit area, numerous water development projects have been commissioned all over the world. Extension of irrigation to the arid regions, however, usually has led to an increase in the area affected by shallow water tables and to

intensifying and expanding the hazard of salinity. The United States Salinity Laboratory (U.S.S.L.) Staff (1954), pioneering the research work on salt affected soils, suggested to consider the problems related to 1) salinity 2) permeability and 3) specific ion toxicity, while evaluating the quality of water for irrigation. Ayers (1977), working on the quality of irrigation waters in India, also opined the similar way.

While classifying the salt affected soils of Kangra district of Gujarat state, Kanwar and Sehgal (1962) noticed that the canal water caused the salt problem due to a high watertable which brought the salts up, that were earlier distributed throughout the profile. While comparing canal and ground water, in causing the potential salt buildup in the soils of arid and semi-arid regions of India, Bhumbra (1981) found that in case of former, salinity problems arose due to waterlogging, while in case of the latter, salinity and/sodicity of underground water caused the menace.

2.2 Characterization and Classification of Salt affected soils.

As emphasized earlier, end uses of studying characteristics of salt-affected soils, particularly from agriculture point of view, are their classification and reclamation. The properties for which the salt affected soils are most commonly examined have been discussed in brief as follows.

2.2.1 Electrical conductivity [EC]

At the field level, though the salinity measurements have been attempted using salinity sensors, four electrode probes, electromagnetic [EM] induction sensors and time - domain reflectometry [TDR] , because of the limitations these methods are often associated with (Rhoades, 1984), the method of U.S.S.L Staff (1954) has found wide application. In this method, the amounts of dissolved salts in water or soil extracts are usually determined by measuring electrical resistance (Ohms) or its reciprocal, the electrical conductance (mhos or Siemens).

Since crops differ greatly in their tolerance to salinity, critical salt concentration soils, below which crops suffer seriously, is not uniform and varies depending upon the soil conditions. Earlier it was considered that the plants begin to be seriously affected when the salt concentration in the soil exceeds 0.1 per cent. However, later the U.S.S.L. Staff (1954) fixed an EC of 4.0 dS m^{-1} as the critical value.

In an investigation of salt affected soils, occurring in the northern parts of Gujarat, Barde and Gowalkar (1965) noticed surface soils to be free of salt problems and the EC values increased with the profile depth. In another study, Sharma *et al* (1968) also noticed a similar trend, wherein EC value recorded in surface soil was 3.0 dS m^{-1} and it was as high as 65 dS m^{-1} at a depth of 100cm. On the

contrary, Sahu et al (1986), while characterizing and classifying the saline soils of Orissa, reported that higher amount of salts in the surface of a profile (Motto profile), was due to salt accumulated from the brackish water, particularly during summer season. Whereas in another profile (Keshpur profile), salinity was thought to be arising because of high ground water table, that resulted due to close proximity of chilka lake and an impervious bedrock stratum underneath. Similar results have been reported by many other authors in various parts of India (Misra and Sharma, 1968; Mathur et al, 1968; Jain and Saxena, 1975 ; Mediratta et al., 1985).

Sahu and Dash (1993), while characterizing salt-affected coastal soils of Astaranga, Orissa, noticed that in profiles protected by embankment, EC values increased with the depth, while in the profile that was unprotected an opposite trend was noticed.

Thus, to put in simple terms, prevailing conditions facilitating accumulation of salts in the surface horizons and the absence of leaching from surface to lower depths, have been found to be responsible for an increasing trend of the EC values in profile stratum upwards, while leaching of salts by irrigation water to the deeper layers and absence of rapid capillary rise have been thought to give rise to surface horizons free of salt problems.

2.2.2 Soil reaction (pH)

Saline soils generally have a pH less than 8.5. In these soils the presence of electrolytes and negative absorption of anions are known to decrease the thickness of the double layer and suppress the hydrolysis of adsorbed Na^+ to some extent. As a result, the hydroxyl (OH^-) ion concentration goes down, leading to a reduced pH (Bear, 1964).

On the other hand, alkali or sodic soils are often associated with very high pH values. Kamil and Shainberg (1968) observed a higher pH in the absence of salts and attributed it to the production of more Al^{3+} ions on clay surface as a result of increased dehydroxylation of Al-complex. These Al^{3+} ions caused more Na^+ ions to hydrolyze into solution, leading to a higher soil pH. According to Nakayama (1970), high pH value is caused in field conditions by Na bicarbonate - carbonate minerals present in alkali soils, which precipitate Ca and Mg carbonate during evaporation and lead to increase in the sodium adsorption ratio (SAR) of solution. The higher concentration of sodium carbonate in alkali soils, which is the cause of high pH, was suggested to be originating by the reaction of exchangeable Na and CaCO_3 in low CO_2 and low salt system (Cruz -Romero and Coleman, 1975).

Samples from sodic soils of Karnal (Haryana) were investigated for the depthwise trend of soil pH by Kanwar and Sehgal (1962). They noticed that soil pH values were found to increase with the profile depth, which was quoted to be because

of fluctuating watertable and higher concentration of Na^+ -salts. Similar trends have been reported by Govindarajan et al, (1969) and Poonia and Bhumbra, (1973). However, in clay-loam and clayey soils studied by Mediratta et al, (1985), the pH values decreased down the profile, indicating the start of sodiumization process from the upper layers. In addition to the above-said definite trends, an irregular trend may also be observed, as noticed by More et al (1988) in the salt-affected soils of Purna Command Area of Maharashtra.

Tiwari et al (1983) reported that the sodic soils in Kanpur region of Uttar Pradesh have high pH. The pH of the soils varied from 8.5 to 10.3. Such high pH of soils was attributed to the presence of soluble sodium carbonate and bicarbonate.

2.2.3 Nature of soluble salts

Plant response to saline and sodic environment is an interplay of a number of edaphic factors which are often independent also. Ground water composition, seepage of salts from upper area and contribution from parent material are the major factors that determine nature and quantities of soluble salts in the soil solution. The determination of these salts and their component ions becomes important from the fact that in case of saline soils, they cause adverse effects through osmosis causing reduced water uptake, while in alkali soils,

the direct toxic effect of Na^+ or the effect of latter in soil dispersion, leads to crop growth being seriously affected.

The composition of soluble salts and the nature of salt affected soils is highly dependent on the rainfall characteristics of an area. Bhargava *et al* (1980) reported that a) around a rainfall of 750 mm, carbonates and bicarbonates are the dominant anions followed by chlorides and sulphates; b) around isohyets of 500-550mm mixed anionic composition with $\text{SO}_4\text{-Cl-CO}_3$ (including HCO_3) or $\text{SO}_4\text{-CO}_3\text{-Cl}$ are common and c) below 300 mm isohyete Cl and SO_4 dominate with only traces of CO_3 . These observations suggest that in addition to the factors said earlier, the quantity of precipitation also plays a decisive role in determining the nature and amounts of salts present in soil solution.

Agarwal and Rammoorthy (1970), while investigating the morphological and chemical properties of black and red soils from various parts of India, observed that in black soil region the Cl-SO_4 ratio was higher in surface layers than in normal soil. This observation indicated the accumulation of Cl^- owing to evaporation and protection from further leaching, due to heavy texture of soils. The process of evaporation when rapid, as in case of arid and semi - arid regions, leads to concentration of CO_3^{-2} and HCO_3^- in the soil solution. With the increase in concentration of the latter, Ca^{2+} and Mg^{2+} are precipitated and rendered less soluble. This phenomenon, which

greatly reduces the activity of Ca^{2+} and Mg^{2+} and increases that of Na^+ , is responsible for development of sodic soils (Kanwar and Kanwar, 1968). However, between CO_3^{2-} and HCO_3^- , the adsorption of Na due to former is more than that due to latter, at same level of salt concentration.

Bhadrapur and Rao (1977), in a study of salt-affected black soils occurring in the command of Tungabhadra Project, Karnataka, noticed that the electrical conductivity and concentration of ions, except sulphate, decreased as the profile depth increased. The lower concentration of SO_4^{2-} in the upper parts of the soil body was suggested to be on account of its lower mobility and lower solubilities of calcium and magnesium sulphates.

Levy and Feighonbaum (1977) indicated that increased soluble sodium upon dilution was due to its replacement mainly by calcium and magnesium. Bhadrapur and Seshagiri Rao (1979) opined that water soluble cations decreased with depth in the salt-affected soils.

In the sodic soils of Kanpur region of Uttar Pradesh, carbonate was the dominant anion followed by bicarbonate, chloride and sulphate in all the profiles, but when bicarbonate was dominant the other ions followed the order : chloride, carbonate and sulphate (Tiwari et al., 1983).

In some salt-affected soils of Bijapur district, Karnataka, sodium was found to be the dominant cation, followed by calcium and magnesium, while sulphate was the dominant anion in soil water extracts. The tendency of sulphate to accumulate in the surface layers was attributed to the presence of sodium sulphate in surface layers, which is highly soluble compared to sulphates of calcium and magnesium (Ballolli, 1987).

Chloride was the dominant anion followed by sulphate whereas bicarbonate content exceeded chloride in sodic profiles of Purna command area of Maharashtra (More et al., 1988).

Sharma and Jha (1989), in comparative studies on salt-affected soils of Indo - Gangetic plain, observed that the pH of saturation extract varied between 8.6 and 10.1, increasing with depth in alkali profile and showing an opposite trend in saline - alkali profile, indicating the dispersion and downward movement of sodium clay in the alkali soils. Further, it was noticed that in salt affected soils, the sequence of soluble cations was : $\text{Na} > (\text{Ca} + \text{Mg}) > \text{K}$, while in normal soils the order was : $(\text{Ca} + \text{Mg}) > \text{Na} > \text{K}$. The higher K content in alkali soils than in other soils was due to alkaline hydrolysis of soil minerals. Among anions, bicarbonates were the dominant, followed by sulphates in salt affected soils, while a reverse order was evident in normal soils. Formation of sodium carbonate and bicarbonate, which favoured sodium adsorption on the exchange complex, was thought to be the main

factor involved in sodiumization of the soils investigated (Pal and Mandal, 1980).

2.2.4 Exchangeable cations and ESP

Amounts and proportions of the various exchangeable cations present in soils markedly influence the physical and chemical properties of soils, their status being dependent on various factors like mineralogy, status of soluble cations, concentration of electrolytes and others.

Seghal *et al*, (1968) reported that the exchangeable calcium and magnesium content in soils of Sutlaj river basin, Punjab, decreased with depth and the values were 6.6 and 2.0 and 2.2 and 0.4 me / 100 g soils, respectively at surface and at one metre depth.

The status of exchangeable cations and exchangeable sodium percentage of a soil depend upon various factors like status of soluble cations, concentrations of electrolytes, the type of minerals etc. In tropical soils, exchangeable calcium and magnesium are found in excess over exchangeable sodium or exchangeable potassium (El - Swaify and Sindale, 1970).

Paliwal (1972) stated that the nature and amount of cations in the soluble form determine the adsorption of cations on the basis of their relative chemical activity, affinity and soluble product on the main exchange complex. While studying the preferential adsorption of divalent cations

over monovalent cations, he also found it related to cation exchange capacity (CEC) of soils. Preference for adsorption of divalents increased as soil CEC increased, while at lower CEC values, monovalents were more preferably adsorbed. So, when CEC increases with depth, it is to be expected that the ESP values would decrease.

In equilibration studies on some Vertisols, occurring in Malaprabha Project Area, Karnataka, Nadakarni (1975) noticed an inverse relationship between CEC and ESP. In the upper layers of soils, associated with lower CEC values, more sodium was adsorbed, while reverse was the case in lower horizons wherein soils had high CEC. Deshpande (1985) and Ballolli (1987) also made similar observations and attributed this trend of decrease in ESP with depth to increase in CEC values, favouring the preferential adsorption of divalent cations, leading to a decrease in SAR value with depths. The decrease in ESP profile stratum downwards, which has also been reported by many other workers Kuri (1979), Srinath (1979) and Mediratta et al, (1985) , may also indicate the initiation of process of sodiumization of soil from surface downwards.

Tiwari et al (1983) reported that sodium constitutes the majority of total cations at lower horizons in most of the salt-affected soils studied.

2.2.5 ESP and SAR

Determination of sodicity and alkali status of soils are important for basing amendment requirement of soils on scientific lines. In the literature, values of exchangeable Na^+ content in excess of the charge capacity of the soil (CEC) have been obtained by using conventional ammonium acetate method (Kanwar and Bhumbra, 1969). The abnormal exchange behavior of alkali soils has been attributed to the occurrence of sodium compounds that are relatively insoluble in water but are soluble in normal salt solutions, such as ammonium acetate to Na fixation (Babcock, 1960) and to the presence of Na - Zeolites (Suhultz *et al*, 1964). Recently, it has been shown by Sposito and Levesque (1985) that the Silver Hill illitic clay specimens had a time-dependent fixation of sodium that did not exchange with calcium but could be replaced by ammonium ions.

To overcome the limitations and eliminate sources of error in determination of CEC of alkali soils, Polemio and Rhoades (1977) developed a two-step procedure involving i) the saturation of exchange sites with 60% ethanolic solution of 0.4 N NaOAc - 0.1 N NaCl, pH 8.2 and ii) extraction of sodium saturated soil with 1 N $\text{Mg}(\text{NO}_3)_2$, pH 7.0. Gupta *et al*. (1985) have further modified this procedure to eliminate errors due to i) alterations in the ion sieve and steric hindrance properties of zeolites by the use of alcoholic solution and ii) release of Na from zeolite minerals in $\text{Mg}(\text{NO}_3)_2$, pH 7.0,

extracting solution. This modern procedure eliminated the use of alcohol and reduced the extraction of non - exchangeable sodium from Zeolite minerals by raising the pH of $\text{Mg}(\text{NO}_3)_2$ solution from 7.0 to 8.6. Although the two improved methods described above seem to be extremely superior over conventional procedure, their reliability needs, however, vigorous testing on a wide range of alkali soils (Gupta and Abrol, 1990). Exchangeable sodium was appreciably higher than predicted from the SAR of the applied water, rich in Mg (Mg / Ca ratio > 1). This is because most soils have greater selectivity for Ca than for Mg, implying that at comparable SAR values, higher ESP would be observed for Mg - Na systems than for Ca - Na systems. Calcareousness and texture of soils also influence the ionic preferences of the two divalent cations (Giridhar and Yadav, 1982).

Under Indian condition also the disagreement between ESP predicted by U.S Salinity Laboratory Staff (1954), equation and actual ESP have been reported (El-seewier et al., 1977).

2.2.6 Classification of salt - affected soils.

The term salt - affected soils conveys a very limited information to a soil scientist, engineer or any other user. Hence, numerous classifications and soil grouping systems have been used for the purpose of definition, characterization, problem identification and amelioration of salt-affected soils.

After scanning the literature one finds that terms saline, alkaline and saline - alkali have often been used to describe salt-affected soils eventhough prevalent nomenclature in East Europe, Russia, Canada and few other countries also employ terms like solonchak, solonetz, soda - solonchak, etc.

Bulk of the scientific community in India uses the well known definitions of U.S. Department of Agriculture (U.S.S.L. Staff, 1954), wherein the pHs (pH of saturated soil paste), E_{ce} (Electrolyte conductivity of saturation extract in dS m^{-1}) and ESP are taken as the basis for classification. According to this system of classification, in a saline soil the threshold E_{ce} is 4 dS m^{-1} , pH is less than 8.5 and ESP less than 15, while in a sodic soil the pH exceeds 8.5, ESP 15 or more but E_{ce} is less than 4 dS m^{-1} . The next class, saline-sodic soils, is a combination of the above two classes.

When salinity and sodicity occur together, as in many saline - sodic soils (containing neutral salts), limited evidence suggested that the effect of two factors on plant growth is non-additive and non - interactive, and the growth is limited primarily by salinity effects (Largerwerff and Holland, 1960). Regardless of SAR in solution, it is the toxic excess of neutral salts in saline - sodic soils that prevent the normal growth of plant. Many saline - sodic soils contain soluble carbonates besides the excess of neutral salts. Such soils manifest alkali soil properties. It is, therefore, only prudent that the saline - sodic soils containing no soluble carbonate

be grouped and managed as saline soils and the rest of them grouped and managed like alkali soils (Gupta and Abrol, 1990).

Although an ESP of 15 has been used to divide a sodic soil from a non - sodic soil, it has been considered too high by Australian scientists and same is the experience from salt affected Vertisols of India (Shanmuganathan and Oades, 1983). Therefore, a considerable lower limiting value of ESP=6 has been suggested for soils with an abundance of fine clay and lacking in soluble weatherable minerals, to maintain eletrolyte concentration of soil solution during leaching.

Bhargava *et al* (1976) have grouped salt-affected soils occurring in India into the following two categories.

1. Alkali soils : Soils with pH more than 8.5, ESP of 15 or more and predponderance of carbonates and bicarbonates of sodium. The E_{Ce} is limitless if originating from salts capable of alkali hydrolysis, otherwise less than 4 dS m^{-1} at 25°C. Abrol *et al* (1980) have suggested that pHs of 8.2 is more realistic diagnostic criterion for distinguishing sodic from non - sodic soils.
2. Saline soils : Soils having pHs less than 8.5, ESP less than 15 and preponderance of chlorides and sulphates of sodium, calcium and magnesium (except gypsum). The E_{Ce} is more than 4 dS m^{-1} at 25°C.

However, some overlaps of the above two categories conforming to saline - alkali soils have been noticed in the Indo - Gangetic plains and in soils where brackish ground

waters are used. Therefore, in a broad sense, Szabolcs (1989) has grouped salt - affected soils as follows :

1. The saline soils that develop under the influence of sodium salts with nearly neutral reaction.
2. The alkali soils that develop under the influence of eletrolytes capable of alkali hydrolysis, mainly Na_2CO_3 and NaHCO_3 .
3. Acid sulphate soils composed mainly of $\text{Al}_2(\text{SO}_4)_3$ and $\text{Fe}_2(\text{SO}_4)_3$ salts and
4. Other types of salt-affected soils, such as strongly degraded alkali soils, sub-soil salinization and potential salinization.

2.3 Physical properties of salt - affected soils :

The permanence of irrigated agriculture and the reclamation of salt - affected soils depend upon the basic understanding of the behaviour of the soil physical properties. The profiles of same kind of soil may have contrasting physical properties as a result of differences in field management or of cultivation of one site and preservation of soil in virgin state on the other hand (Pandey and Pathak, 1975).

Adverse physical properties of salt-affected soils, and especially the sodic soil, are related to swelling of colloids, dispersion of soil particles and consequent sealing of surface soil. With the purpose of defining soil behaviour during leaching and reclamation, the properties

related to water retention and transmission characteristics of salt - affected soils have been widely researched (Singh, 1989). However, such efforts with particular emphasis on salt - affected black soils appear to be lacking. Therefore, whatever the information available has been pooled and presented comprehensively herebelow :

The permeability of the soil is a function of the square of the pore radii. Therefore, pore size distribution in the soil largely controls leaching efficiency. Though aggregate failure or slaking has been found to be the major cause of reduction in the size of large conducting pores and resultant decrease in hydraulic conductivity (HC) of saline soils during leaching (Abu - Sharar *et al.*, 1987), there is a lack of consensus among researchers on the processes leading to aggregate failure, dispersion of clay and blocking of conducting pores. Introduction of a solution of weaker electrolyte strength into the soil solution, as in case of leaching, will have two immediate consequences : i) the clay of aggregate will swell, especially if it is smectite type, and weakens the bonds and ii) osmotic bursting of aggregates will occur as the high concentration gradient, created between the dilute external solution and the more concentrated solution within the aggregate, rushes in more water (Keren and Singh, 1988).

Researchers also differ on causes for reduction in size of conducting pores during leaching of salt - affected soils. McNeal *et al* (1966) attributed the clogging of soil

pores to in situ mineral swelling or the migration of clay platelets which accumulate in soil pores. Frenkel et al. (1978), suggested that the plugging of pores occurred mainly due to dispersed clay particles. Whatever be the reason, the reduction in size of conducting pores always leads to reduction in hydraulic conductivity (HC) and hence the poor water retention and transmission characteristics.

2.3.1 Bulk density and porosity.

The bulk density, expressed as the ratio of mass of dried soil to its total volume, is related to soil texture. Also called apparent density, BD of most soils ranges from 1.0 g cm^{-3} for clays to 1.8 g cm^{-3} for sands, corresponding to the range of 62.5 to 112 lb ft^{-3} and a porosity (fraction of soil volume not occupied by soil particles) of 0.60 - 0.30 per cent.

While studying the physical properties of alluvial soils of Uttar Pradesh, Gupta and Narain (1971) regrouped the soils of Unao district into five genetic types as i) Ganga low land ii) Ganga flat land iii) Ganga upland iv) Central low land and v) Saline alkali soil. In case of Unao soil type 5, being saline-alkali in nature, surface was loamy underlaid by heavy textured clay loam to clay followed by a dense Kankar layer at a metre depth. The BD of the soil was high, above 1.6 g cm^{-3} in all the horizons and volume of the pores below 40 per cent. The subsoil remained deflocculated, due to which the capillary pores formed more than 90 per cent of the total pore space and the amount of aeration pores seldom exceeded three per cent of

the soil volume. The above quoted investigation clearly brings out the prominence of soil texture in determining its BD and total porosity as well as the aeration capacity and hence, the suitability of soil for crop production.

In another study of physical properties of normal and salt affected soils of Uttar Pradesh by Pandey and Pathak (1975), soil physical properties were observed to be both as precursor and after effect of salt accumulation. The highest value of BD and the lowest volume of total pore space were noticed in sub-soils. The non - capillary porosity for surface soils lied between 10.6 and 12.2 per cent (normal cultivated), 4.5 and 9.8 per cent (salt - affected cultivated), and 5.1 and 5.8 per cent (salt - affected virgin), which greatly reduced in the zone of maximum compaction. The possible reason for this trend was suggested to be the deflocculation of soil, due to which the capillary pores occupied greater portion of the total porespace.

Mathan and Mahendran (1993), while studying the HC of Vertic Huplustalfs of Tamil Nadu in relation to soil properties, observed a decreased saturated hydraulic conductivity (K_s) at lower depths compared to surface layers and the saturated HC had a positive correlation with coarse sand. The BD of soils, varying between 1.5 and 1.7 g cm^{-3} , showed significantly negative correlation with K_s , while total and non-capillary porosity showed no relation. They also noticed a significant negative correlation of ESP with K_s ,

which was attributed to dispersion and deflocculation of aggregates in presence of high exchangeable sodium.

In a study, directed to obtain information about sodiumization of Alfisols in Indo - Gangetic plain of Bihar, Singh and Mishra (1994) found a general increase in BD with the depth, which was attributed to be due to dispersion and migration of clays and clogging of pores in subsoils. Similarly, Mathan and Mahendran (1994), while studying the physical properties of Tamil Nadu soils, varying in texture from low clay to heavy clay, also found that with increase in depth, BD had increased. This trend might be due to more of dispersible clay content, which migrated and clogged the porespace.

In soils of Upper Krishna Project Area, derived from diverse parent materials, Doddamani *et al.* (1994) noticed the lowest BD of 1.1 g cm^{-3} in soils derived from limestone, which was attributed to finer fraction of soil. In all the soils investigated, BD was found to increase slightly with the depth, which was due to decreased organic carbon content and increasing shearing strength with the depth.

2.3.2 Maximum water holding capacity (MWHC) and volume expansion (VE)

Coutls (1929) observed that the MWHC was correlated significantly and positively with clay content, while Luthane and Staple (1953) observed fine textured clayey soils to be high in MWHC than silt loam, silt + clay and clayey loam soils.

Ghildyal and Satyanarayana (1965) noticed that with increase in clay content, the MWHC also increased, on the other hand, sand content and MWHC had an inverse relationship. It was also observed that as the clay content increased from 9.7 to 47.4 per cent, the volume expansion also increased extensively from 3.4 to 41.8 per cent.

Irrespective of the soils and their texture, the water holding capacity of Uttar Pradesh soils generally increased with the depth and was attributed to increasing clay content with the depth (Pandey and Pathak, 1975). Hirekurubar (1989) also noticed a similar trend in Vertisols of northern Karnataka, and he also observed a significant and positive correlation between clay content and volume expansion.

Doddamani *et al* (1994), while working on the soils of Upper Krishna Project Area, noticed that both the water retention capacity and available water increased with profile depth. The silt and clay content, individually and in combination, had a direct relation in determining the soil water characteristics.

2.4 Available nutrient status in salt-affected soils.

In salt - affected soils, the accumulated salts may reduce nutrient availability or cause specific ion toxicity. The nutritional effects of salts in sodic soils are generally caused by high soil pH, but the manner in which high exchangeable Na produces nutritional disorders is not very clear.

Bower and Wadleigh (1949) showed that the unfavourable nutritional effect of exchangeable sodium are independent of its effect on soil pH. Whether it is nutritional or physical effects caused by sodium are more detrimental, depends upon the nature of crop and extent of deterioration in soil physical properties (Singh, 1989).

The relative significance of the above-said factors has evaded categorical answer, owing to wide variation in nutrient status of sodic soils and inability of crops to withstand poor soil physical conditions.

As a consequence of high pH and salt content in salt-affected soils, there would be change in the form, solubility, availability and efficiency of nutrient elements. These aspects have been reviewed with respect to individual nutrients and presented herebelow :

2.4.1 Available nitrogen (N)

Salt -affected soils usually contain less than 0.1 per cent organic matter, are thus poor in native available N and hence respond to applied N. The efficiency of N fertilizers in sodic soils is low, partly due to volatalization of the element as ammonia and partly due to suboptimal plant growth, that results owing to poor soil physical properties. Nitant and Dargan (1974) reported that complete hydrolysis of N-fertilizer at a pH of 10.4 was delayed by four days when compared with normal soils. This means a gradual supply of

NH_4^+ ions to the solution phase and consequently more volatilization losses. Soils with high pH values have shown positive influence on NH_3 losses (Fenn and Kissel, 1973). Losses of ammonia were higher at the field moisture range and in unreclaimed soils, and generally ranged between 30 and 65 per cent, depending upon the level of N applied and prevailing soil moisture conditions in alkali soils. (Bhardwaj and Abrol, 1978 ; Rao and Batra, 1983). Symbiotic N-fixation is also retarded in salt-affected soils, which is due to sensitivity of microbes to high alkalinity and reduced growth of host plants. Bhardwaj (1975) reported that though rhizobia could survive and multiply in sodic soils with pH as high as 10.0, the host plant was sensitive at this pH. It is limited by the pH effect per se or due to reduced energy source caused by reduction in the growth of host plants. Due to these reasons, 15-20 per cent extra application of N fertilizer is recommended in sodic soils (CSSRI, 1979).

In a study of distribution of available N in semi-arid region of Haryana, Goyal and Mahendra Singh (1987) observed that soils, mostly low in clay content and low to very low in organic carbon, showed a decreasing trend of available N with depth. There was a linear relationship between organic carbon and available N, meaning the latter was found to accumulate in surface layers. A lower clay content in these soils, with pH 7.8 to 8.5, was responsible for low CEC and thus low retention of ammonium ions on exchange complex, leading to lower N availability.

Kanthaliya and Bhatt (1991), while studying the relationship between organic carbon and available N in soils of Rajasthan, found that these two were positively and significantly correlated. The close relationship of available N with organic matter was attributed to adsorption of ammonical N by humus complex in the soil.

2.4.2 Available phosphorus (P)

Alkali soils have been reported to contain high amounts of available P. Due to presence of higher amounts of Na_2CO_3 in alkali soils, Ca-bound P ($\text{Ca}_3(\text{PO}_4)_2$) which is the predominant form of P in alkali soils, undergoes double decomposition forming Na_3PO_4 and CaCO_3 , thereby sharply increasing the Olsen's extractable - P (Chhabra et al, 1981).

While studying the availability of P in salt-affected soils of Uttar Pradesh, Bina Devi and Varshney (1979) noticed that available P was positively and significantly associated with soil pH and moisture. High pH of salt-affected soils which might have contributed to enhanced mineralization of organic P, was supposed to be the cause. The reduction in available P subsequent to rainy season was attributed to the interference caused by enhanced concentration of various ionic species in the soils and decreased moisture status due to rapid evaporation.

Verma *et al* (1983), in an investigation on suitability of using organic carbon as an index of available P in alluvial soils of Uttar Pradesh, found that the organic carbon was not significantly correlated with active P forms, such as Al-P, Ca-P and Fe-P and also available P. The lack of association observed was attributed to the fact that the available P mostly includes inorganic P fractions, which do not correlate with organic carbon. Hence latter did not appear to be a feasible index of P-availability.

Availability of P in air - dry and waterlogged conditions was compared in salt - affected soils by Srivastava and Srivastava (1993). It was noticed that in air dry soil, with the increase in pH from 7.3 to 10.8, availability of P linearly increased. The increased availability of P in soils saturated with sodium was attributed to accelerated dissolution of Ca-P compounds or complexes resulting from the creation of sink for Ca. In contrast to an increase of 6.1 ppm in available P with unit increase in soil pH observed in air-dry soils, the increase per unit pH increase in waterlogged soils was 7.5 ppm.

2.4.3 Available potassium (K)

The availability of K in alkali soils has generally been reported to be adequate, the main reason being the predominance of K - rich micaceous minerals in soils of arid and semi-arid regions (Kapoor *et al.*, 1981), Also, dissolution

of muscovite saturated units releases large amounts of K in sodic soil environments (Pal, 1985).

Kanthaliya and Bhatt (1991) obtained a positive but non-significant correlation between available K and organic carbon. The positive relation was attributed to release of K from organic complexes. But since the correlation was non-significant, it was concluded that the organic carbon could not be used as an index of K availability in the soils investigated.

2.4.4 DTPA - extractable micronutrient cations

Since developed by Lindsay and Norvell (1978), the DTPA test for available micronutrients has been in use in soil testing laboratories, because Diethylene Triamine Penta-Acetic Acid (DTPA) is capable of extracting available Zn, Cu, Fe and Mn simultaneously.

2.4.4.1 DTPA extractable Zinc (Zn)

In normal soils the relation between Zn solubility and pH has been negative, means an increase in soil pH decreases the availability of Zn (Shaw and Dean, 1952). On the other hand, in highly alkali soils, available Zn was observed to increase with sodicity even more than in the reclaimed soils (Takkar and Nayyar, 1981). However, Gupta and

Abrol (1990) were of the opinion that at high pH, poor physical properties and retrogradation of precipitation limited the adequate supply of Zn to crops. Whereas, coprecipitation and specific adsorption reactions appeared to mitigate the benefit of increased Zn solubility at lower pH values during desodification. Therefore, regular application of Zn in small doses to each of the crops grown in a sequence has been a more efficient nutrient management practice, since a single and heavy basal dosage of Zn application to soil leads to transformation of available Zn to stable mineral bound Zn forms (Singh and Abrol, 1986).

In a study of effect of soil properties on DTPA extractable micronutrients in some soils of Punjab, Arora and Sekhon (1981) found that the extractability of Zn reduced with increase in pH. Low solubility of Zn soil complexes was found to be major cause of Zn deficiency in these soils. Joshi *et al.* (1983) also found a similar trend in fine-textured soils of Rajasthan, which they attributed to the higher CEC of these soils, leading to adsorption of more Zn.

While studying distribution of micronutrients in calcareous soils, Jha (1984) noticed that in case of lowlying areas, DTPA extractable Zn was positively and significantly correlated with organic carbon and clay, while in arid soils of Rajasthan, no such relation was found (Sharma *et al.*, 1985).

While investigating the distribution of available micronutrients as related to soil properties, Kuldeep Singh *et al.* (1988) noticed that the surface horizons of soils had higher available Zn, which in most cases decreased with depth. Available Zn was not much influenced by physico-chemical properties. However, partial regression coefficients showed that the variability in available Zn was primarily controlled by pH, EC, CaCO_3 , organic carbon and soil Fe content.

Joshi *et al.* (1988), in their study on available micronutrients in salt-affected soils of Rajasthan, noticed that these soils contained adequate amounts of available Zn (averaging 0.6 to 0.8 ppm), considering the critical limit of 0.6 ppm.

Sharma and Lal (1992) found that DTPA Zn was negatively correlated with soil pH. They indicated that as the solubility of Zn^{2+} and its adsorption to organic matter and sesquioxides are pH dependent, decrease in available Zn with increasing pH is expected. The study also revealed a positive association of DTPA extractable Zn with organic carbon, while its correlation with clay content was positive but not always significant.

2.4.2.2 DTPA extractable Copper (Cu)

In alkali soils of Punjab, Arora and Sekhon (1981) observed that, except for the soils that were very low in silt and organic matter, available Cu was always more than one ppm.

On the basis of 0.2 ppm Cu as the critical limit, all the soils were found to be well supplied with this nutrient. The positive correlation of DTPA extractable Cu with organic matter and silt contents suggested that Cu held as easily exchangeable Cu on the silt particles and that complexed by organic matter were the main sources. The positive correlation between available Cu and organic carbon was attributed to the formation of stable complexes with natural complexing agents in soil solution, the ratio of chelated Cu to Cu^{2+} being 10^3 to 10^4 in alkaline soils (Schnitzer, 1969).

Joshi *et al* (1983) noticed that in soils of Rajasthan, available Cu increased with texture becoming finer and no other soil property had a significant influence on soil Cu availability.

While studying depthwise distribution of micronutrients in soils of Haryana, Kuldeep Singh *et al.* (1988) observed that in some profiles higher amount of available Cu was associated with surface layers, while in others subsurface horizons had a higher content. The partial regression coefficients indicated the dominant influence of CEC and silt on Cu availability.

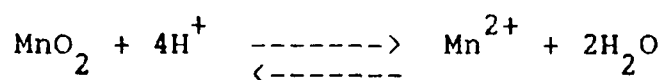
In saline and non - saline soils of Rajasthan, available Cu was almost similar (0.6 to 2.0 ppm and 0.7 to 1.9 ppm, respectively). Considering 0.2 ppm of Cu, the critical limit, soils were well supplied with available Cu. In salt-affected soils, available Cu was negatively influenced by clay

content, while in normal soils, none of the soil parameters studied was found related with this form of Cu (Joshi *et al*, 1988).

In a study on vertical distribution of micronutrients in semi - arid soils of Haryana, Sangwan and Kuldeep Singh (1993) observed an irregular distribution pattern of Cu with profile depths, which was due to weak pedogenic manifestation and alluvial nature of these soils. Available Cu was significantly and positively correlated with organic carbon, clay and CEC. However, multiple regression revealed the dominant influence of clay and CEC on soil Cu availability.

2.4.4.3 DTPA extractable Manganese (Mn)

One of the factors that influences the availability of Mn is soil pH. At high pH, the element is converted into less available manganic oxides (Mn^{3+} and Mn^{4+}). The dependence of form of Mn on soil pH is illustrated by the equation :



Pasricha and Ponnampereuma (1976) found that the effect of NaCl and $NaHCO_3$ on the kinetics of water soluble Mn were similar to those of Fe^{2+} , i.e., NaCl increased the concentration of Mn ions, while $NaHCO_3$ dispressed them at all stages of submergence.

Arora and Sekhon (1981) found that in soils of Punjab, DTPA extractable Mn varied from 5.1 to 51.5 ppm. Considering the critical limit of one ppm, all the soils were abundantly supplied with Mn. Soil pH and CaCO_3 negatively contributed to the available Mn in soils and the effect of pH was more pronounced. The authors concluded that the main source of DTPA Mn was inorganic phase, i.e., various types of Mn bearing minerals, whose nature is dependent upon soil pH, because as reported by Geering *et al* (1969), the concentrations of Mn^{2+} in soil solution are quite variable and strongly influenced by oxidation - reduction reactions.

The influence of soil texture on available micronutrient status was revealed by Sharma *et al.* (1985) in arid zone soils of Rajasthan. Medium and fine - textured soils generally had higher availability of Mn than the sandy soils. Further, DTPA-Mn was positively and significantly correlated with clay, silt and organic carbon.

Kuldeep Singh *et al.* (1988) noticed adequate available Mn in soils of Haryana, which sharply reduced as the profile depth increased. Partial regression coefficients showed the dominant role of silt, clay, available Cu and Fe in increasing Mn availability, while soil pH, EC and CaCO_3 were found to have a depressing effect.

In soils of semi - arid regions of Haryana, Sangwan and Kuldeep Singh (1993) noticed that available Mn either decreased with depth or it followed an irregular pattern of

distribution. Soil pH was found to play a major role in Mn availability, the increase in which generally brought down the Mn availability.

2.4.4.4 DTPA extractable Iron (Fe)

The occurrence of iron chlorosis has been often noticed in sodic and calcareous soils (Katyal and Sharma, 1980), wherein solubility of Fe is conditioned by soil pH and CaCO_3 content. In addition, P and Ca have also been suggested as causative factors (Singh, 1989).

Arora and Sekhon (1981) noticed negative and significant relation between DTPA - Fe and pH and free CaCO_3 .

In a study on influence of physiography on distribution of micronutrients in calcareous soils of Bihar, Jha (1984) noticed that the DTPA-Fe showed no definite trend of distribution in the profiles, which was probably because of young nature of the alluvial deposits.

Sharma and Yadav (1986) reported that in the sodic soils of Indo - Gangetic plains, the available Fe either remained constant or showed continuous increase with depth in the soil profiles. The increased accumulation of Fe at lower depths was attributed to high annual precipitation in those areas.

According to Kuldeep Singh *et al* (1988), available Fe content in soils of Haryana was around 2 ppm, a critical limit proposed by Takkar and Randhwa (1978). These soils had

higher Fe in the surface than at lower depths, probably owing to higher organic carbon and lower CaCO_3 in surface layers. This was substantiated by the significant positive correlation ($r=0.37^*$) and negative correlation ($r=-0.34^*$) between available Fe and organic carbon and CaCO_3 content, respectively.

In profiles of semi - arid soils of Haryana, similar to Mn, available Fe also either decreased or showed irregular pattern of distribution with depth. It was noticed that available Fe was significantly and negatively influenced by EC and CaCO_3 and significantly positively by available Mn and Cu.

MATERIAL AND METHODS

III . MATERIAL AND METHODS

The particulars relating to collection and preparation of soil samples and the analytical methods adopted in the investigation are detailed in this chapter.

3.1 Collection and preparation of soil samples

The black soil region, representing the Upper Krishna Project (UKP) Area of Gulbarga district of Karnataka, was selected for the investigation. In all, seven profiles were exposed in the said region, which were as follows :

Profile	I	(P1)	-----	Hebbal (B)
Profile	II	(P2)	-----	Hebbal (K)
Profile	III	(P3)	-----	Havinal
Profile	IV	(P4)	-----	Agricultural Research Station, Kawadimatti
Profile	V	(P5)	-----	Farmer's field, Kawadimatti
Profile	VI	(P6)	-----	Islampur
Profile	VII	(P7)	-----	Devapur.J

The soils collected belong to the taxonomic order Vertisols and sub - order Usterts. The profiles P1 to P5 (Tumkur series) have developed on granite gneiss, while P6 and P7 (Kagalgomb series) are formed on lime-stone parent material. Physiography of the region is nearly flat and the drainage, generally imperfect, Further, details regarding taxonomic classification of the soils and physiography of the region have been briefed in Appendix I, and the locations of the soil sampling sites are depicted in Fig 1(a), 1(b) and 1(c).

N



SCALE : 1" = 60 Miles.

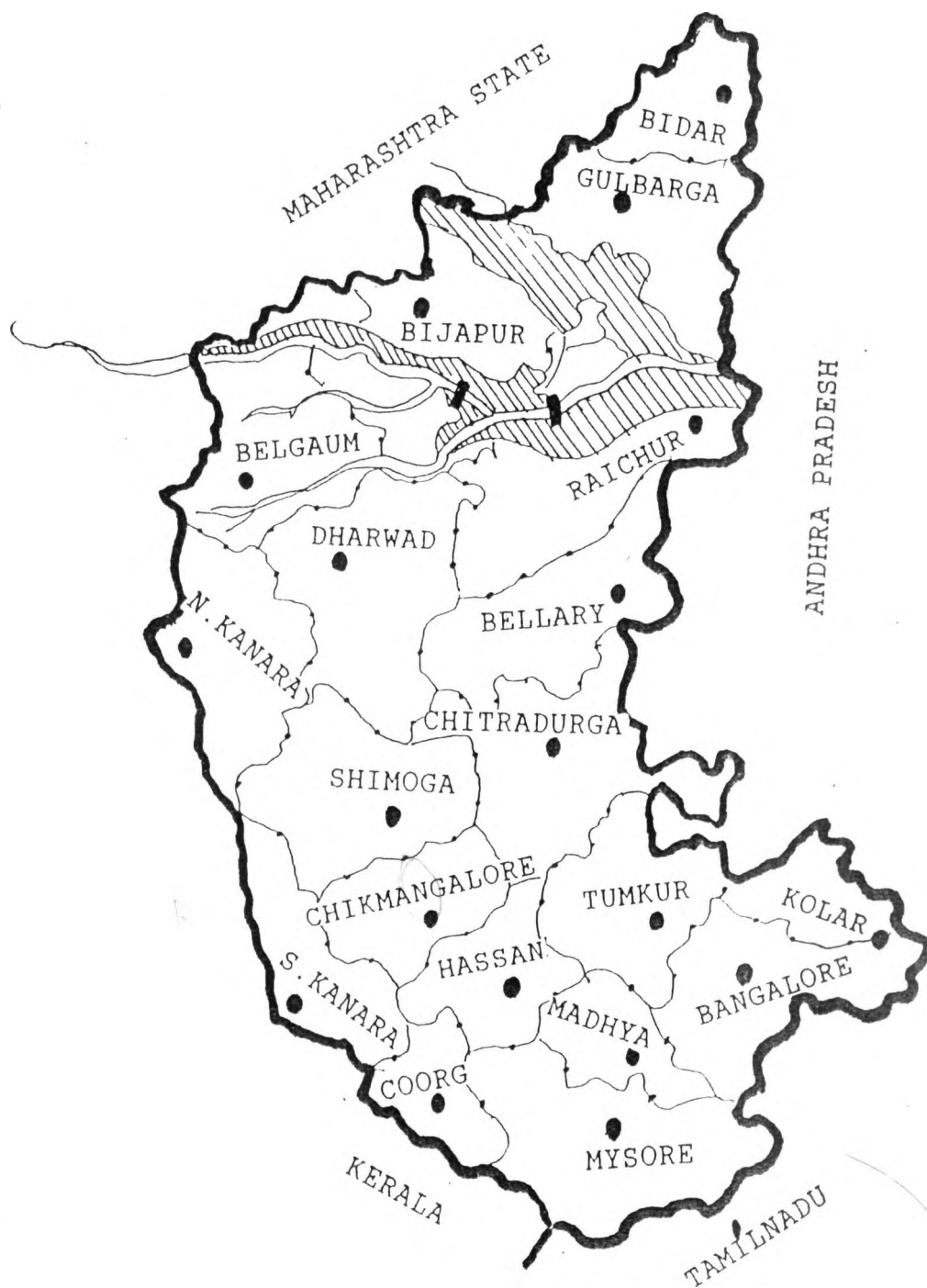
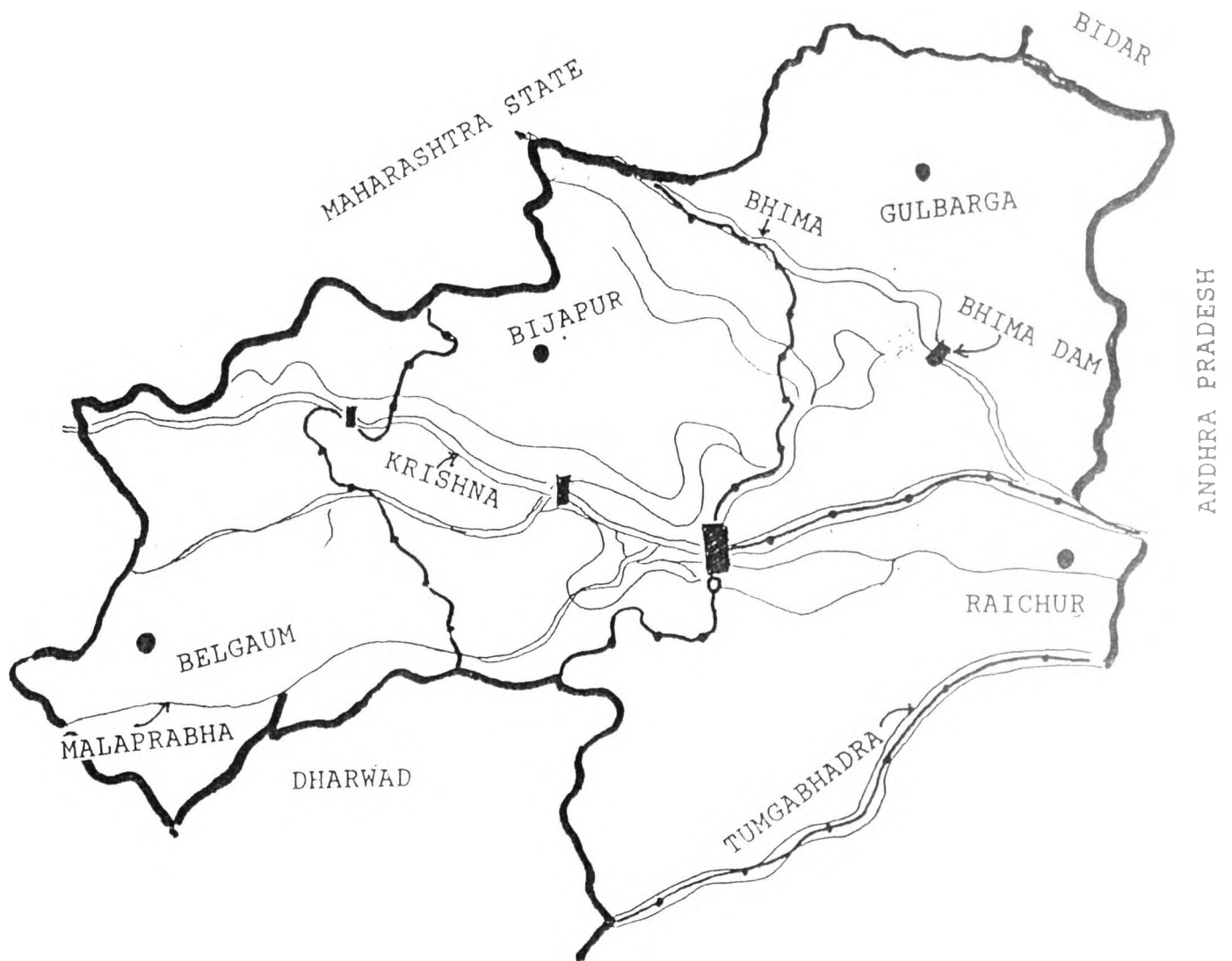


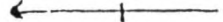
Fig 1 (a). Map of Karnataka

SCALE: 1" = 30 Miles

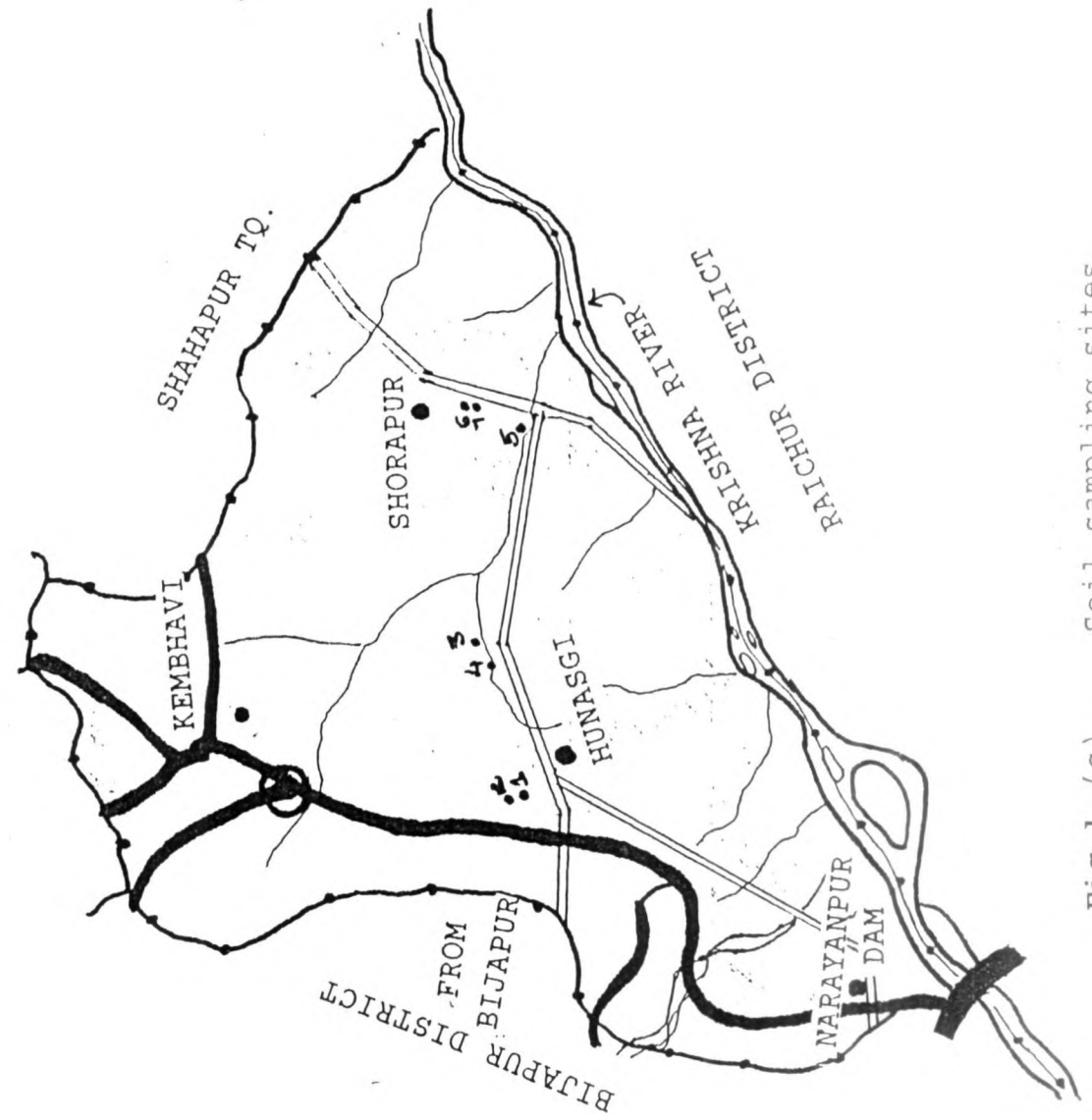


Figl(b). Index map of Upper Krishna Project

N



SCALE: 1" = 8 Miles



LEGEND

1. DEVAPUR (J)
2. ISLAMPUR
3. HEBBAL (K)
4. HEBBAL (B)
5. HAVINAL
6. KAWADIMATTI (I)
7. KAWADIMATTI (II)

Fig.1 (c). Soil sampling sites

From the seven profiles exposed thus, soil sample collection was made at six depths of each profile, viz 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cm, making a total of 42 samples.

The samples obtained so were dried in shade, gently powdered and sieved to pass through 2 mm - sieve. Analysis for various parameters, in accordance with the objectives of the study, was carried out on representative sub samples drawn from the bulk samples. The details of the procedures of soil analysis are briefed in Table 1.

Table 1. Methods of analysis of soil samples

Sl. No.	Estimation	Author	Remarks
I. Physical Properties			
1.	Particle size distribution	Piper (1950)	International Pipette method
2.	Bulk density	Black (1965)	Core sampler method
3.	Particle density	U.S.S.L. Staff (1954)	Pycnometer method
4.	Porosity	Black (1965)	$St = 100 - (1 - Db/Dp)$ St=Total porosity Db=Bulk density Dp=Particle density
5.	Maximum water holding capacity	Sankaram (1966)	Using Keen Raczkowski brass cup
6.	Volume expansion	Sankaram (1966)	Using Keen Raczkowski brass cup
II. Chemical properties			
7.	Soil reaction (pH)	Jackson (1967)	1:2.5 soil water suspension using pH meter (systronics model-331)
8.	Electrical conductivity (EC)	Jackson (1967)	1:5 soil water extract using conductivity bridge (systronics model-304)
9.	Cation exchange capacity (CEC)	Black (1965)	Sodium saturation method
10.	Exchangeable cations	Black (1965)	Ammonium acetate saturation method
	$Ca^{++} + Mg^{++}$	Black (1965)	Versenate titration
	Na^{+} and K^{+}	Black (1965)	Flame photometer (Systronics model-MKIII)

Sl. No.	Estimation	Author	Remarks
11.	Water soluble cations	U.S.S.L. Staff (1954)	1:5 soil water extract
	$\text{Ca}^{++} + \text{Mg}^{++}$	U.S.S.L. Staff (1954)	Versenate titration
	Na^+ and K^+	U.S.S.L. Staff (1954)	Flame photometer (systronics model-MK III)
12.	Water soluble anions	U.S.S.L. Staff (1954)	1:5 soil water extract
	CO_3^{--} and HCO_3^-	U.S.S.L. Staff (1954)	Titration against standard H_2SO_4 using methyl orange and phenolphthalein indicators
	SO_4^{--}	Black (1965)	Precipitation as barium sulphate and measurement of turbidity with spectrophotometer (systronics model-106)
	Cl^-	U.S.S.L. Staff (1954)	Titration against standard AgNO_3 using K_2CrO_4 indicator
III Available nutrient status			
13.	Available-N	Subbaiah and Asija (1956)	Alkaline permanganate method
14.	Available-P	Olsen <i>et al.</i> (1954)	Extraction with NaHCO_3 (pH 8.5)
15.	Available-K	Black (1965)	Extraction with ammonium acetate and estimation using flame photometer (systronics model-MK III)
16.	Micronutrients	Lindsay and Narvell (1978)	Extraction with DTPA reagent and determination through Atomic Absorption spectrophotometer (AAS) (Shimadzu model-A.60)

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The black soil region, representing the Upper Krishna Project (U.K.P) Area of Gulbarga district of Karnataka, was selected for the study and results obtained are presented in this chapter under the following headings :

- 4.1 Physical properties of salt - affected soils.
- 4.2 Chemical properties of salt - affected soils and
- 4.3 Nutrient status of salt - affected soils.

4.1 Physical properties of salt - affected soils.

4.1.1 Particle size distribution

The data on particle size distribution are presented in Table 2.

The sand content in the soils studied ranged between 16.71 and 38.50 per cent. The lowest sand content was observed in the profile P6 (Islampur, 15 - 30 cm) and the highest value in the last depth of profile P3 (Havinal). Regarding depth wise distribution of sand in the profiles studied, there was a decrease in percentage of sand upto third or fifth depth in majority of profiles. In profile P1 (Hebbal (B)), P2 (Hebbal (K)), P3 (Havinal) and P5(Farmers field, Kawadimatti), it decreased upto third or fourth depth, whereas , in profile P7 (Devapur.J), it decreased upto fifth depth and increased at further depth. In remaining profiles, the trend was not definite.

Only profile P3 (Havinal) recorded a decrease in silt fraction upto fourth depth, showing an indefinite trend of distribution in the subsequent depths. Whereas, in profile P2 (Hebbal (K)), it decreased upto third depth and increased further. On the other hand, in profile P6 (Islampur), it increased upto third depth and decreased in remaining layers. However, no definite trend was observed in rest of the profiles.

Clay content in the soils studied was found to range between 38.32 and 64.26 per cent. In all the profiles and at all the depths, the clay fraction accounted for more than 38 per cent of the mechanical constituents. In case of profiles P1 (Hebbal (B)), P2 (Hebbal (K)), P3 (Havinal), P5 (Farmers field, Kawadimatti) and P7 (Devapur.J), it increased upto fourth or fifth depth and decreased thereafter. In remaining profiles, no consistent trend of its distribution with the depth was noticed.

Textural Class

The sand fraction in the soils varied between 16.71 and 38.50 per cent and that of silt, between 12.30 and 31.42 per cent. The clay content was more than 38 per cent throughout in all the profiles.

By referring to textural triangle, these profiles are classified into clayey texture, except last depth of profile P2 (Hebbal (K)) which was clay loam.

Table 2 - Particle size distribution in soils

Profile No	Location	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class
P1	Hebbal(B)	0-15	27.54	17.12	55.20	clay
		15-30	24.05	16.29	59.51	clay
		30-60	20.40	17.63	61.83	clay
		60-90	18.42	17.22	64.26	clay
		90-120	25.35	12.30	62.32	clay
		120-150	29.75	12.86	57.28	clay
P2	Hebbal(K)	0-15	36.75	21.34	42.38	clay
		15-30	36.03	16.89	47.18	clay
		30-60	34.01	16.80	49.07	clay
		60-90	29.64	20.22	49.92	clay
		90-120	32.51	22.22	45.12	clay
		120-150	35.38	25.81	38.32	clayloam
P3	Havinal	0-15	31.89	23.16	44.79	clay
		15-30	30.02	22.09	47.13	clay
		30-60	28.09	19.86	51.18	clay
		60-90	28.47	15.15	55.91	clay
		90-120	31.28	15.15	53.08	clay
		120-150	38.50	12.44	48.85	clay
P4	ARS, Kawadi- -matti	0-15	26.28	21.12	51.91	Clay
		15-30	26.42	23.63	48.69	Clay
		30-60	24.79	17.93	53.69	Clay
		60-90	34.94	24.02	54.46	Clay
		90-120	30.66	18.64	50.51	Clay
		120-150	31.46	21.78	46.37	Clay
P5	Farmer's field Kawadimatti	0-15	30.98	25.83	43.08	Clay
		15-30	29.73	22.47	47.73	Clay
		30-60	24.09	24.08	51.78	Clay
		60-90	24.09	20.00	55.91	Clay
		90-120	33.38	17.73	48.85	Clay
		120-150	35.01	20.19	44.79	Clay
P6	Islampur	0-15	34.72	19.40	44.12	Clay
		15-30	16.71	22.47	59.32	Clay
		30-60	23.93	26.83	48.79	Clay
		60-90	19.84	26.76	53.12	Clay
		90-120	26.95	21.91	50.56	Clay
		120-150	36.49	20.78	42.38	Clay
P7	Devapur.J	0-15	38.12	20.00	40.27	Clay
		15-30	37.09	17.23	45.13	Clay
		30-60	30.03	20.59	48.97	Clay
		60-90	21.27	29.02	49.56	Clay
		90-120	16.97	31.42	51.28	Clay
		120-150	27.89	30.47	41.35	Clay

4.1.2 Bulk density

All the soils under investigation were high in bulk density, with the values ranging between 1.38 and 1.60 Mg m^{-3} . The lowest bulk density was recorded in the surface layer of profile P1 (Hebbal (B)), while the highest, in the last depth of profile P4 (ARS, Kawadimatti). By and large, bulk density increased with depth in all the profiles. In profile P5 (farmer's field, Kawadimatti), the sequence of increase with the depth was, 1.43 (0-15 cm), 1.47 (15-30 cm), 1.51 (30-60 cm), 1.53 (60-90 cm), 1.54 (90-120 cm) and 1.56 Mg m^{-3} (120-150 cm). While in profiles P1 (Hebbal (B)), P4 (ARS, Kawadimatti) and P6 (Islampur), it increased with the depth from 1.38 to 1.54, 1.51 to 1.60 and 1.45 to 1.53 Mg m^{-3} , respectively. Whereas, in profile P2 (Hebbal (K)), it increased upto third depth, exhibiting an indefinite trend of distribution in the subsequent layers. In the remaining profiles, however, no definite trend between distribution of bulk density and profile depth could be made out (Table 3).

4.1.3 Particle density (Table 3)

Particle density of the soils studied ranged between 2.54 and 2.78 Mg m^{-3} . The lowest particle density value was recorded in the last depth of profile P5 (Farmer's field, Kawadimatti) whereas the highest, in the last depth of profile P2 (Hebbal (K)). Its distribution with the depth in majority of the profiles did not follow a definite pattern. However, in profile P2 (Hebbal (K)), from second depth (15-30 cm) onwards, it increased throughout.

4.1.4 Porosity

Porosity of the soils under investigation varied between 38.58 and 47.81 per cent (Table 3). The lowest porosity value was recorded in the last depth of profile P5 (farmer's field, Kawadimatti), while the highest, in the surface layer of profile P5 (Farmer's field, Kawadimatti). In general, a decreasing trend of porosity with depth was noticed in majority of the profiles. In profile P2 (Hebbal (K)), the decreasing pattern was, 47.01 (0 - 15 cm), 46.64 (15 - 30), 45.76 (30 - 60 cm), 45.56 (60 - 90 cm), 44.96 (90 - 120 cm) and 44.73 per cent (120 - 150 cm). In profile P1 (Hebbal (B)), P3 (Havinal), P5 (Farmer's field, Kawadimatti) and P6 (Islampur), it decreased with the depth from 46.51 to 41.67, 46.82 to 43.70, 47.81 to 38.58 and 46.30 to 44.57 per cent, respectively. In profile P4 (ARS, Kawadimatti) and P7 (Devapur.J) the trend was not definite.

4.1.5 Maximum water holding capacity (MWHC)

As could be visualised from Table 3, maximum water holding capacity of the soils under investigation ranged between 40.12 and 73.21 per cent. The lowest MWHC was recorded in the surface layer of profile P1 (Hebbal (B)) and the highest, in the fourth depth of profile P4 (ARS, Kawadimatti). In profile P1 (Hebbal (B)), P2 (Hebbal (K)), P5 (Farmer's field, Kawadimatti), P6 (Islampur) and P7 (Devapur.J), it increased upto fourth depth and showed a decreasing trend thereafter. No definite trend could be made out in profile P3 (Havinal) and P4 (ARS, Kawadimatti).

Table 3 - Physical properties of soils.

Profile No	Location	Depth (cm)	B.D --- Mg m ⁻³ ---	P.D ---	Porosity (%)	Maximum Water hold -ing capacity (%)	Volume Expansion (%)
P1	Hebbal (B)	0-15	1.38	2.58	46.51	40.12	38.65
		15-30	1.43	2.63	45.63	41.25	40.01
		30-60	1.44	2.62	45.04	44.86	41.78
		60-90	ND	2.61	ND	46.78	43.42
		90-120	1.50	2.64	43.18	45.92	43.70
		120-150	1.54	2.64	41.67	43.15	42.04
P2	Hebbal (K)	0-15	1.42	2.68	47.01	46.78	38.17
		15-30	1.43	2.68	46.64	50.82	41.58
		30-60	1.47	2.71	45.76	53.86	42.12
		60-90	1.47	2.73	45.56	58.95	44.12
		90-120	1.52	2.75	44.96	54.22	44.11
		120-150	1.53	2.78	44.73	50.82	38.08
P3	Havinal	0-15	1.42	2.67	46.82	58.77	39.70
		15-30	1.42	2.65	46.42	60.95	42.89
		30-60	ND	2.62	ND	62.20	44.86
		60-90	ND	2.68	ND	62.20	46.55
		90-120	1.46	2.70	43.85	58.40	45.02
		120-150	1.52	2.71	43.70	57.92	42.11
P4	ARS, Kawadi-matti	0-15	1.51	2.70	44.07	71.54	39.82
		15-30	1.53	2.69	43.12	70.90	41.23
		30-60	ND	2.71	ND	70.82	43.93
		60-90	1.54	2.68	42.54	73.21	45.47
		90-120	1.55	2.60	40.39	71.09	43.40
		120-150	1.60	2.70	40.74	69.40	41.10
P5	Farmer's field Kawadimatti	0-15	1.43	2.74	47.81	41.25	34.69
		15-30	1.47	2.71	45.76	42.12	35.49
		30-60	1.51	2.68	43.66	44.86	38.76
		60-90	1.53	2.71	43.54	45.92	40.26
		90-120	1.54	2.60	40.70	43.15	37.57
		120-150	1.56	2.54	38.58	42.71	35.99
P6	Islampur	0-15	1.45	2.70	46.30	50.82	40.86
		15-30	1.47	2.71	45.76	55.77	42.98
		30-60	1.49	2.74	45.62	58.95	46.32
		60-90	ND	2.74	ND	60.95	47.08
		90-120	1.52	2.76	44.93	59.18	45.12
		120-150	1.53	2.76	44.57	57.92	44.52
P7	Devapur. J	0-15	1.40	2.59	45.95	53.86	37.88
		15-30	1.42	2.65	46.41	54.22	39.52
		30-60	1.42	2.60	45.39	58.40	41.11
		60-90	1.46	2.67	45.32	62.20	44.87
		90-120	1.50	2.70	44.44	61.18	42.73
		120-150	1.53	2.70	43.33	60.37	40.64

ND : Not determined as that particular soil depth consisted mostly canckers.

4.1.6 Volume expansion

The values of volume expansion of the soils under investigation varied between 34.69 and 47.08 per cent. The lowest volume expansion was recorded in the surface depth of profile P5 (Farmer's field, Kawadimatti), while the highest, in the fourth depth of profile P6 (Islampur). In all profiles, it increased upto third or fourth depth, showing a decrease thereafter (Table 3).

4.2 Chemical properties of salt - affected soils

4.2.1 Soil reaction

All the soils were alkaline in reaction, with pH values more than 7.50 and values ranging between 7.50 and 9.10. In general, the pH values increased with increasing depth in most of the soil bodies, except in P1 (Hebbal (B)) and P6 (Islampur). In profile P2 (Hebbal (K)) the order of pH increase with depth was, 8.35 (0-15 cm), 8.40 (15-30cm), 8.60 (30-60cm), 8.65 (60-90 cm), 8.75 (90-120 cm) and 8.85 (120-150 cm). In profiles P3 (Havinal), P4 (ARS, Kawadimatti), P5 (Farmer's field, Kawadimatti) and P7 (Devapur. J), it increased with the depth from 7.85 to 8.40, 8.45 to 8.90, 7.50 to 8.45 and 8.35 to 9.10 respectively. Whereas, in profile P1 (Hebbal (B)), it decreased upto third depth, with the higher depths recording lower value.

4.2.2 Electrical conductivity

The electrical conductivity values of 1:5 soil water extract have shown wide variation in the soil profiles and ranged between 1.0 to 6.4 dS m⁻¹ (Table 4). The lowest electrical conductivity was recorded in the last depth of profile P4 (ARS, Kawadimatti), while the highest in the surface depth of profile P5 (Farmer's field, Kawadimatti). In general, electrical conductivity has decreased with increasing depth. In profile P2 (Hebbal (K)), the order of decrease with depth was 4.1 (0-15 cm), 4.0 (15-30 cm), 3.3 (30-60 cm), 2.1 (60-90 cm), 1.5 (90-120 cm) and 1.1 dS m⁻¹ (120-150 cm), while in profile P1 (Hebbal (B)), P3 (Havinal), P4 (ARS, Kawadimatti), P5 (Farmer's field, Kawadimatti) and P7 (Devapur.J.), it decreased with depth from 5.4 to 4.9, 6.1 to 4.1, 4.2 to 1.0, 6.4 to 4.0 and 4.1 to 1.1 dS m⁻¹, respectively. However, no definite trend was observed in case of profile P6 (Islampur).

4.2.3 Organic carbon

From Table 4, it is seen that organic carbon content was more in surface depths than the subsurface depths in majority of the profiles. The values ranged between 0.09 and 0.63 per cent. The lowest organic carbon content was recorded in the last depth of profile P3(Havinal), while the highest, in the surface layer of profile P1 (Hebbal (B)). In profile P2 (Hebbal (K)), the order of decrease with depth was; 0.54(0-15cm), 0.45(15-30cm), 0.33 (30-60 cm), 0.21 (60-90 cm), 0.18 (90-120 cm) and 0.12 per cent (120-150 cm). While in profile P1

Table 4. pH, salinity status and organic carbon of soils

Profile No.	Location	Depth (cm)	pH	EC (dS m ⁻¹)	OC (%)
P1	Hebbal (B)	0-15	7.85	5.4	0.63
		15-30	7.75	5.3	0.42
		30-60	7.65	5.2	0.40
		60-90	7.80	5.1	0.33
		90-120	8.10	5.0	0.30
		120-150	8.25	4.9	0.20
P2	Hebbal (K)	0-15	8.35	4.1	0.54
		15-30	8.40	4.0	0.45
		30-60	8.60	3.3	0.33
		60-90	8.65	2.1	0.21
		90-120	8.75	1.5	0.18
		120-150	8.85	1.1	0.12
P3	Havinal	0-15	7.85	6.1	0.36
		15-30	8.00	5.0	0.21
		30-60	8.05	4.8	0.16
		60-90	8.10	4.7	0.15
		90-120	8.35	4.5	0.10
		120-150	8.40	4.1	0.09
P4	ARS, Kawadi-matti	0-15	8.45	4.2	0.33
		15-30	8.60	2.2	0.45
		30-60	8.70	1.8	0.36
		60-90	8.75	1.6	0.21
		90-120	8.80	1.3	0.15
		120-150	8.90	1.0	0.12
P5	Farmer's field Kawadimatti	0-15	7.50	6.4	0.42
		15-30	7.75	6.2	0.24
		30-60	7.95	6.0	0.21
		60-90	8.35	5.9	0.21
		90-120	8.40	5.4	0.12
		120-150	8.45	4.0	0.12
P6	Islampur	0-15	7.90	4.9	0.60
		15-30	7.90	4.6	0.54
		30-60	8.10	4.4	0.42
		60-90	8.25	4.4	0.39
		90-120	7.70	4.6	0.23
		120-150	8.10	4.0	0.21
P7	Devapur J.	0-15	8.35	4.1	0.62
		15-30	8.60	2.4	0.60
		30-60	8.80	2.2	0.51
		60-90	8.85	1.9	0.33
		90-120	8.90	1.2	0.25
		120-150	9.10	1.1	0.18

(Hebbal (B)), P3 (Havinal), P6 (Islampur) and P7 (Devapur.J.), it decreased with depth from 0.63 to 0.20, 0.36 to 0.09, 0.60 to 0.21 and 0.62 to 0.18 per cent. In the remaining profiles, no definite trend between distribution of organic carbon and profile depth could be made out.

4.2.4 Cation exchange capacity

A perusal of Table 5 indicates that, in general, CEC has increased upto third or fourth depth, registering a decrease thereafter. The values varied from 32.19 to 59.16 c mol(p^+) kg^{-1} . The lowest value was observed in the surface layer of profile P7 (Devapur.J) and the highest, in the fourth depth of profile P2 (Hebbal (K)). In profile P1 (Hebbal (B)), P2(Hebbal (K)), P3(Havinal), P5 (Farmer's field, Kawadimatti), P6(Islampur) and P7 (Devapur.J), it increased upto third or fourth depth and decreased thereafter. However, no definite trend was observed in case of profile P4 (ARS, Kawadimatti).

4.2.5.1 Exchangeable cations (Table 5)

Calcium + Magnesium

Exchangeable calcium and magnesium are the dominant bases among all the exchangeable bases. The values varied from 24.0 to 46.8 c mol (p^+) kg^{-1} . The lowest value was observed in the surface layer of P7 (Devapur.J) and the highest, in profile P2 (Hebbal (K)) at 60-90 cm depth. In profile P1 (Hebbal (B)), P2 (Hebbal (K)), P3 (Havinal), P5 (Farmer's field, Kawadimatti), P6 (Islampur) and P7 (Devapur.J), these exchangeable cations increased upto third or

fourth depth and decreased in the subsequent horizons. In profile P4 (ARS, Kawadimatti) exchangeable Ca + Mg did not show a regular trend of depth distribution.

Potassium

Exchangeable potassium is very low in all profiles studied. It ranged between 0.15 and 0.62 c mol (p^+) kg^{-1} . The lowest exchangeable K content was noticed at surface layer of profile P4 (ARS, Kawadimatti), whereas the highest value was recorded in surface layer of profile P7 (Devapur.J). The exchangeable K in profile P1 (Hebbal (B)) and P5 (Farmer's field, Kawadimatti) decreased with depth from 0.53 to 0.25 and 0.43 to 0.21 c mol (p^+) kg^{-1} , respectively. Its distribution with the depth in majority of the profiles did not follow a definite trend.

Sodium

Though present in appreciable amounts in certain profiles, the exchangeable Na content never exceeded the exchangeable Ca + Mg content. It varied from 3.04 to 14.11 c mol (p^+) kg^{-1} . The lowest value was noticed in the surface layer of profile P1 (Hebbal (B)) and the highest, in profile P4 (15-30 cm, ARS, Kawadimatti). In profile P1 (Hebbal (B)), P3 (Havinal), P5 (Farmer's field, Kawadimatti) and P7 (Devapur.J), it increased upto third or fourth depth and decreased thereafter, while in profile P6, it increased upto fifth depth, showing a reduction at further depth. There was no definite trend in the remaining profiles with respect to exchangeable Na.

Table 5 - Exchangeable cations, CEC and ESP values at different depths

Profile No.	Location	Depth (cm)	Ca ++	Mg ++	K +	Na + -1	CEC -----	ESP (%)
P1	Hebbal (B)	0-15	31.4		0.53	3.04	34.80	8.74
		15-30	35.0		0.42	3.69	39.15	9.43
		30-60	37.2		0.37	4.12	41.76	9.87
		60-90	40.4		0.34	4.56	45.24	10.08
		90-120	39.4		0.27	3.91	43.50	8.99
		120-150	39.2		0.25	3.69	42.24	8.74
P2	Hebbal (K)	0-15	30.6		0.52	6.51	39.15	16.63
		15-30	41.0		0.31	8.90	52.20	17.05
		30-60	42.2		0.21	8.46	53.07	15.94
		60-90	46.8		0.42	9.98	59.16	16.87
		90-120	42.4		0.34	8.25	53.07	15.55
		120-150	31.8		0.37	7.60	41.76	18.20
P3	Havinal	0-15	29.4		0.48	3.26	34.80	9.37
		15-30	31.0		0.24	5.74	38.15	15.05
		30-60	41.8		0.25	7.60	50.46	15.06
		60-90	36.4		0.32	6.67	44.24	15.08
		90-120	32.2		0.43	4.99	38.28	13.04
		120-150	28.2		0.36	3.26	33.06	9.86
P4	ARS, Kawadi- -matti	0-15	36.8		0.15	8.03	45.24	17.75
		15-30	42.6		0.26	14.11	58.29	24.21
		30-60	37.6		0.28	9.33	48.72	19.15
		60-90	37.2		0.35	13.24	51.33	25.79
		90-120	38.8		0.29	8.03	48.72	16.48
		120-150	38.2		0.34	7.11	46.98	15.13
P5	Farmer's field kawadimatti	0-15	30.0		0.43	3.47	33.06	10.50
		15-30	32.6		0.39	4.56	37.41	12.19
		30-60	37.8		0.36	5.64	43.50	12.97
		60-90	39.6		0.31	6.29	46.11	13.64
		90-120	39.0		0.27	4.99	44.24	11.03
		120-150	37.0		0.21	3.69	40.89	9.02
P6	Islampur	0-15	35.4		0.53	4.12	41.76	9.87
		15-30	37.0		0.50	5.21	44.37	11.74
		30-60	42.0		0.41	5.64	49.59	11.37
		60-90	36.6		0.51	6.94	43.50	15.95
		90-120	35.6		0.21	7.60	42.24	16.80
		120-150	32.8		0.27	4.34	37.41	11.60
P7	Devapur, J	0-15	24.0		0.62	6.08	32.19	18.89
		15-30	25.2		0.41	7.73	33.32	23.20
		30-60	28.4		0.39	9.33	40.02	23.31
		60-90	34.4		0.57	11.00	46.98	23.42
		90-120	33.0		0.27	7.16	42.63	16.80
		120-150	30.4		0.40	5.74	38.28	15.00

4.2.5.2 Exchangeable sodium percentage

Exchangeable sodium percentage values ranged between 8.74 and 25.79. The lowest value was noticed in the surface and last layer of profile P1 (Hebbal (B)) and the highest, in profile P4 (60-90 cm, ARS, Kawadimatti). In profile P1 (Hebbal (B)), P3 (Havinal), P5 (Farmer's field, Kawadimatti) and P7 (Devapur.J), it increased upto third or fourth depth and decreased in the lower horizons. In other profiles, it did not follow any specific pattern with the depth.

4.2.6.1 Water soluble cations (Table 6)

Calcium + Magnesium

Water soluble Ca + Mg content varied between 2.0 and 32.0 me L⁻¹. The lowest value was noticed in the last layer of profile P2 ((Hebbal (K))), while the highest, in the surface layer of profile P5 (Farmer's field, Kawadimatti). The concentration decreased with the depth in profile P2 (Hebbal (K)) which followed the order : 16.6 (0-15 cm), 15.4 (15-30 cm), 14.0 (30-60 cm), 7.0 (60-90 cm), 5.2 (90-120 cm) and 2.0 me L⁻¹ (120-150 cm). While in profile P6 (Islampur) and P7 (Devapur.J), it decreased with depth from 23.4 to 16.8 and 14.0 to 2.4 me L⁻¹, respectively. Whereas, in profile P1 (Hebbal (B)), P4 (ARS, Kawadimatti) and P5 (Farmer's field, Kawadimatti), it decreased upto fourth depth, with no definite sequence in remaining layers. In rest of the profiles, the concentration did not follow a definite sequence.

Potassium

Water soluble potassium is very low in all the profiles studied. It ranged between 0.005 and 0.154 me L⁻¹ and in majority of the profiles, there was no definite pattern in its distribution with the depth. However, in profile P3 (Havinal), P6 (Islampur) and P7 (Devapur.J), it decreased with depth from 0.049 to 0.005, 0.154 to 0.005 and 0.118 to 0.010 me L⁻¹, respectively. The decreasing order at various depths, in profile P3 (Havinal) was : 0.049 (0-15 cm), 0.030 (15-30 cm), 0.028 (30-60 cm), 0.023 (60-90 cm), 0.013 (90-120 cm) and 0.005 me L⁻¹ (120-150 cm). In profile P1 (Hebbal (B)), on the other hand, it decreased upto third depth, showing no definite sequence in remaining layers.

Sodium

Among the cations, water soluble sodium dominated over rest of cations. It varied widely among and also within the profiles. The values ranged between 8.25 and 33.42 me L⁻¹. The lowest value was noticed in the last layer of profile P7 (Devapur.J), while the highest, in profile P5 (30-60 cm, Farmer's field, Kawadimatti). Water soluble sodium decreased with depth in P2 (Hebbal(K)) and the order was: 23.87 (0-15cm), 23.44 (15-30 cm), 19.10 (30-60 cm), 15.19 (60-90 cm), 11.28 (90-120 cm) and 9.11 me L⁻¹ (120-150 cm). While in profile P7 (Devapur.J), it decreased with depth from 26.47 to 8.25 me L⁻¹. On the other hand, in profile P1 (Hebbal (B)), P5 (Farmer's field, Kawadimatti) and P6 (Islampur), water soluble sodium

showed an increase upto third depth and decreased thereafter. In all other profiles, distribution trend was irregular.

4.2.6.2 Water soluble anions

Carbonates and bicarbonates

Water soluble carbonates were present in trace amounts, with the exception of P2 (Hebbal (K)), P4 (ARS, Kawadimatti) and P7 (Devapur.J), which recorded smaller quantities of carbonates at few or all depths. The depth distribution pattern of carbonates, where it was present, was mostly irregular. Concentration of bicarbonates varied from 1.4 to 6.4 me L⁻¹. The lowest water soluble bicarbonates content was recorded in the last depths of profile P2 (Hebbal (K)), while the highest, in the surface layer of profile P6 (Islampur). In rest of the profiles studied, the distribution of bicarbonate did not follow a definite sequence.

Chloride

Among anions, chlorides dominated over the rest in all the profiles, except in the surface layer of profile P3 (Havinal) and P4 (ARS, Kawadimatti). The variation in its concentration among different profiles and also among different depths was very high. The values ranged between 6.5 and 34.5 me L⁻¹. The lowest water soluble chloride content was recorded in the last layer of profile P7 (Devapur.J), while the highest, in

the surface layer of profile P5 (Farmer's field, Kawadimatti). Considering its depth-wise distribution, a decrease in its concentration with the depth was noticed in profile P4 (ARS, Kawadimatti), P5 (Farmer's field, Kawadimatti) and P7 (Devapur.J). In profile P5 (Farmer's field, Kawadimatti), the order of decrease with depth was 34.5 (0-15 cm), 32.0 (15-30 cm), 30.5 (30-60 cm), 27.0 (60-90 cm), 26.0 (90-120 cm) and 22.0 me L⁻¹ (120-150 cm), while in profile P4 (ARS, Kawadimatti) and P7 (Devapur.J), it decreased with depth from 18.5 to 7.0 and 24.0 to 6.5 me L⁻¹, respectively. In profiles P1 (Hebbal (B)), P3 (Havinal) and P6 (Islampur), water soluble chlorides increased upto third or fourth depth. However, no definite trend was observed in case of profile P2 (Hebbal (K)).

Sulphates

Sulphates were the next in order of dominance after chlorides and their concentration varied between 3.0 and 30.9 me L⁻¹. The lowest concentration was noticed in the last depth of profile P2 (Hebbal (K)) and the highest, at the surface depth of profile P3 (Havinal). The concentration of sulphates decreased with the depth in profiles P2 (Hebbal(K)), P3 (Havinal) and P7 (Devapur.J) from 14.6 to 3.0, 30.9 to 9.8 and 11.3 to 4.0 me L⁻¹, respectively. The order of decrease in profile P3 (Havinal) was : 30.9 (0-15 cm), 16.3 (15-30 cm), 12.0 (30-60 cm), 11.8 (60-90 cm), 10.2 (90-120 cm) and 9.8 me L⁻¹

Table 6 - Ionic composition of 1 : 5 Soil-water extracts

Profile	Location	Depth (cm)	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	CO ₃ ⁻²	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻²	SAR	Predicted
No			-----me L ----- ⁻¹			-----me L ----- ⁻¹			----- ⁻¹			ESP
P1	Hebbal (B)	0-15	26.4	0.023		26.91	tr	2.0	28.5	24.6	7.41	8.82
		15-30	25.8	0.018		27.34	tr	4.8	29.0	20.2	7.62	9.07
		30-60	24.2	0.005		28.21	tr	2.0	29.5	21.0	8.11	9.61
		60-90	22.6	0.010		27.78	tr	4.6	26.0	20.4	8.27	9.86
		90-120	24.4	0.008		24.74	tr	2.8	27.0	19.2	7.09	8.42
		120-150	24.6	0.005		24.74	tr	2.6	28.5	18.5	7.05	8.37
P2	Hebbal (K)	0-15	16.6	0.028		23.87	tr	6.0	20.5	14.6	8.29	9.88
		15-30	15.4	0.069		23.44	tr	4.0	23.0	12.9	8.43	10.05
		30-60	14.0	0.038		19.10	0.3	2.2	22.5	08.5	7.21	8.57
		60-90	7.0	0.008		15.19	0.7	2.0	14.0	07.2	8.13	9.68
		90-120	5.2	0.008		11.28	0.6	1.8	10.5	05.0	7.01	8.32
		120-150	2.0	0.008		09.11	0.4	1.4	10.0	03.0	9.11	10.86
P3	Havinal	0-15	30.0	0.049		30.38	tr	2.4	28.0	30.9	7.85	9.35
		15-30	22.4	0.030		26.47	tr	4.0	31.0	16.3	7.90	9.41
		30-60	22.6	0.028		26.91	tr	4.2	32.0	12.0	8.01	9.55
		60-90	22.2	0.023		24.30	tr	2.0	32.5	11.8	7.30	8.68
		90-120	22.4	0.013		23.00	tr	4.0	31.5	10.2	6.87	8.51
		120-150	20.2	0.005		21.70	tr	4.2	27.0	09.8	6.82	8.09
P4	ARS, Kawadi -matti	0-15	16.2	0.015		26.04	0.1	4.0	18.5	20.0	9.14	10.89
		15-30	4.2	0.018		17.79	0.5	2.0	12.5	10.8	12.27	14.41
		30-60	4.0	0.008		14.76	0.7	2.2	10.0	07.2	10.47	12.42
		60-90	2.8	0.015		15.62	0.2	1.6	09.5	07.8	13.24	15.45
		90-120	3.0	0.010		09.98	1.3	1.8	08.0	05.2	08.11	9.67
		120-150	3.0	0.015		09.55	0.9	1.6	07.0	04.5	07.76	9.25

Contd...2

Profile No	Location	Depth (cm)	Ca ²⁺ +Mg ²⁺ me L ⁻¹	K ⁺ me L ⁻¹	Na ⁺	CO ₃ ⁻²	HCO ₃ ⁻ me L ⁻¹	Cl ⁻ L ⁻¹	SO ₄ ⁻²	SAR	Predicted ESP
P5	Farmer's field	0-15	32.0	0.044	32.12	tr	6.2	34.5	24.8	8.03	9.57
		15-30	30.0	0.044	32.55	tr	2.0	32.0	26.4	8.41	10.03
	Kawadimatti	30-60	26.6	0.013	33.42	tr	2.0	30.5	27.2	9.16	10.91
		60-90	25.6	0.008	32.98	tr	2.0	27.0	28.0	9.21	10.97
		90-120	26.0	0.005	27.34	tr	2.2	26.0	24.2	7.57	09.01
		120-150	19.2	0.005	20.40	tr	4.0	22.0	16.5	6.58	07.79
P6	Islampur	0-15	23.4	0.154	24.70	tr	6.4	24.0	19.2	7.23	08.60
		15-30	20.6	0.036	25.17	tr	1.8	24.5	19.7	7.84	09.34
		30-60	18.8	0.026	25.44	tr	2.0	25.0	20.2	8.29	09.88
		60-90	18.4	0.015	25.17	tr	2.2	22.0	19.9	8.31	09.91
		90-120	17.0	0.013	24.04	tr	2.0	25.5	18.3	8.23	09.81
		120-150	16.8	0.005	22.13	tr	4.2	20.0	16.2	7.63	09.09
P7	Devapur.J	0-15	14.0	0.118	26.47	tr	6.0	24.0	11.3	9.91	11.88
		15-30	05.2	0.044	18.23	0.7	4.0	13.0	07.8	11.32	13.37
		30-60	04.8	0.033	17.79	0.4	2.2	12.5	07.4	11.48	13.55
		60-90	04.7	0.026	14.32	1.2	2.0	11.5	07.1	09.36	11.15
		90-120	03.0	0.013	10.42	0.7	1.8	08.0	04.2	08.47	10.10
		120-150	02.4	0.010	08.25	1.8	1.8	06.5	04.0	07.50	08.93

(120-150 cm). On the other hand profile P5 (Farmer's field, Kawadimatti) and P6 (Islampur), water soluble sulphate showed an increase upto third or fourth depth and decreased thereafter. In other profiles, it did not follow any specific pattern with the depth.

4.2.6.3 Sodium adsorption ratio

Sodium adsorption ratio in the profiles studied ranged between 6.58 and 13.24. In profiles P1 (Hebbal (B)), P3 (Havinal), P5 (Farmer's field, Kawadimatti), P6 (Islampur) and P7 (Devapur.J), it increased upto third or fourth depth and decreased thereafter. In other profiles, however, it did not follow a definite trend with the depth.

SAR-ESP Relationship

An attempt was made to verify the adaptability of the U.S.S.L. Staff (1954) equation in predicting the ESP status of the soils under study. Using the equation, ESP values were calculated from SAR values and these predicted values were compared with actually determined ESP values of the soil samples.

In all profiles, predicated ESP values were less than actually determined values.

4.2.6.4 Classification of soils (Table 7)

It is always important to classify the salt - affected soils into saline, saline-sodic and sodic soils,

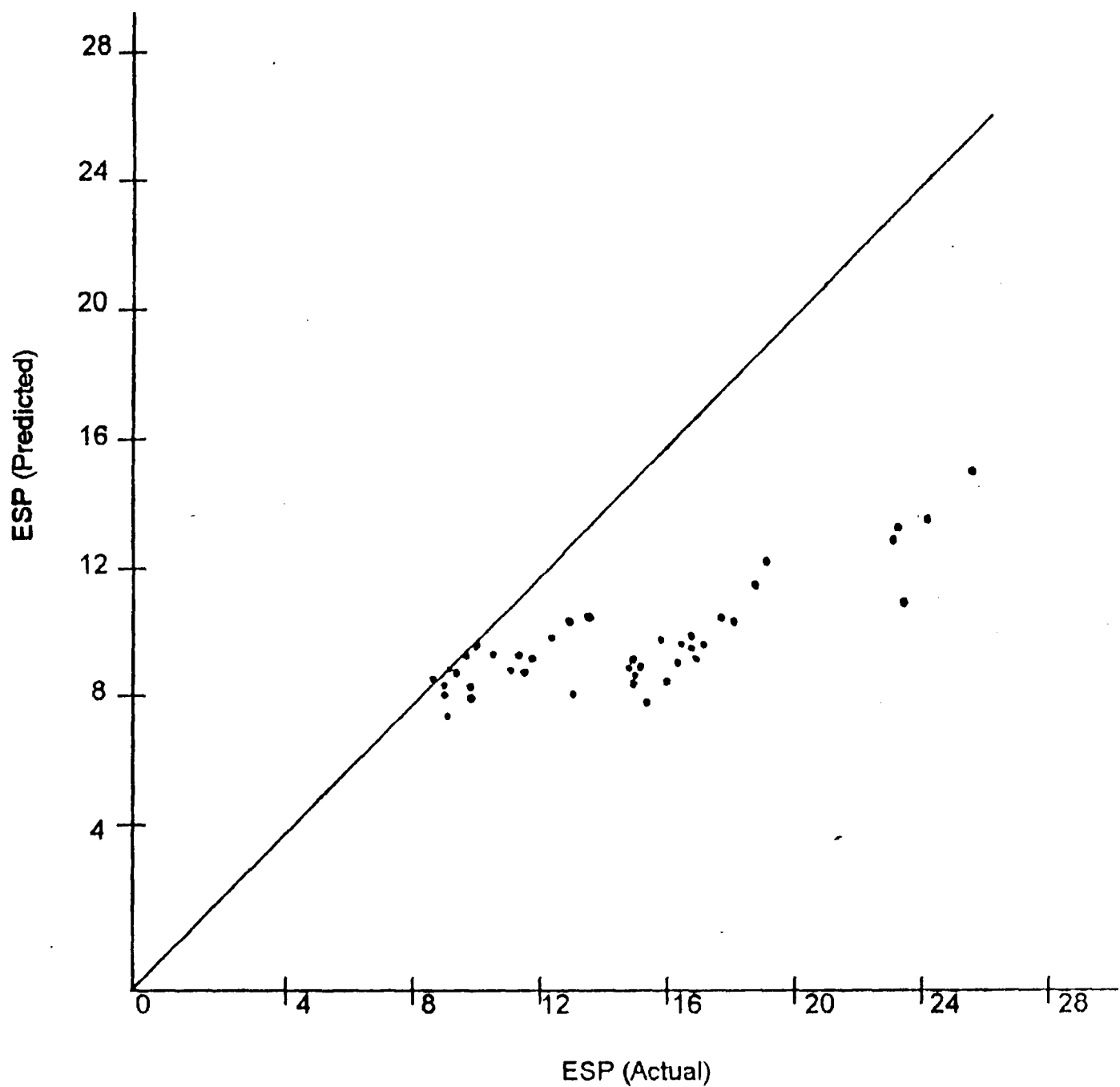


Fig 2 : Relationship between ESP (Actual) and ESP (Predicted)

Table 7 - Classification of soils

Profile No.	Location	Depth (cm)	pH	EC	ESP	Class
P1	Hebbal (B)	0-15	7.85	5.4	8.74	Saline
		15-30	7.75	5.3	9.43	Saline
		30-60	7.65	5.2	9.87	Saline
		60-90	7.80	5.1	10.08	Saline
		90-120	8.10	5.0	8.99	Saline
		120-150	8.25	4.9	8.74	Saline
P2	Hebbal (K)	0-15	8.35	4.1	16.63	Saline-Sodic
		15-30	8.40	4.0	17.05	Saline-Sodic
		30-60	8.60	3.3	15.94	Sodic
		60-90	8.65	2.1	16.87	Sodic
		90-120	8.75	1.5	15.55	Sodic
		120-150	8.85	1.1	18.20	Sodic
P3	Havinal	0-15	7.85	6.1	9.37	Saline
		15-30	8.00	5.0	15.05	Saline-Sodic
		30-60	8.05	4.8	15.06	Saline-Sodic
		60-90	8.10	4.7	15.08	Saline-Sodic
		90-120	8.35	4.5	13.04	Saline
		120-150	8.40	4.1	9.86	Saline
P4	ARS, Kawadi-matti	0-15	8.45	4.2	17.75	Saline-Sodic
		15-30	8.60	2.2	24.21	Sodic
		30-60	8.70	1.8	19.15	Sodic
		60-90	8.75	1.6	25.79	Sodic
		90-120	8.80	1.3	16.48	Sodic
		120-150	8.90	1.0	15.13	Sodic
P5	Farmer's field kawadimatti	0-15	7.50	6.4	10.50	Saline
		15-30	7.75	6.2	12.19	Saline
		30-60	7.95	6.0	12.97	Saline
		60-90	8.35	5.9	13.64	Saline
		90-120	8.40	5.4	11.03	Saline
		120-150	8.45	4.0	9.02	Saline
P6	Islampur	0-15	7.90	4.9	9.87	Saline
		15-30	7.90	4.6	11.74	Saline
		30-60	8.10	4.4	11.37	Saline
		60-90	8.25	4.4	15.95	Saline-Sodic
		90-120	7.70	4.6	16.80	Saline-Sodic
		120-150	8.10	4.0	11.60	Saline
P7	Devapur .J	0-15	8.35	4.1	18.89	Saline-Sodic
		15-30	8.60	2.4	23.20	Sodic
		30-60	8.80	2.2	23.31	Sodic
		60-90	8.85	1.9	23.42	Sodic
		90-120	8.90	1.2	16.80	Sodic
		120-150	9.10	1.1	15.01	Sodic

based on pH, EC and ESP values (Saline soils; pH < 8.5, EC > 4.0 dSm⁻¹, ESP < 15, Sodic soils; pH > 8.5, EC < 4.0 dSm⁻¹, ESP > 15) and Saline-sodic soils; pH > 8.5, EC > 4.0 dSm⁻¹, ESP > 15) because, it will, in turn, help in making suitable recommendations for reclamation of these soils.

Of the profiles studied, P1 (Hebbal (B)) and P5 (Farmer's field, Kawadimatti) had pH < 8.50, EC > 4.0, ESP < 15 throughout the depth and were, therefore, classified as saline.

In case of profiles P2 (Hebbal (B)), P4 (ARS, Kawadimatti) and P7 (Devapur. J) salinity - cum - sodicity was noticed at one or two top depths, while the lower layers were sodic. On the other hand, in P3 (Havinal) and P6 (Islampur), no sodicity was noticed and salinity alone or salinity-cum-sodicity was recorded at different depths.

4.3 Nutritional status of salt - affected soils (Table 8).

4.3.1 Available nitrogen

The available N in the soils ranged between 45.57 and 161.82 Kg ha⁻¹. The lowest available N was recorded in the last depth of profile P4 (ARS, Kawadimatti), while the highest, in the surface layer of profile P3 (Havinal). All the profiles studied come under low status with respect to available nitrogen (< 280 Kg ha⁻¹, low; 280-560 kg ha⁻¹, medium and > 560 kg ha⁻¹, high). In general, available N decreased with increasing depth in all soil bodies, except in profile P5 (Farmer's field, Kawadimatti) and P6 (Islampur). In profile P1 (Hebbal (B)), the

order of decrease with depth was : 142.70(0-15cm), 124.02 (15-30cm), 110.80(30-60cm), 92.13 (60-90cm), 84.02 (90-120cm) and 80.91 Kg ha⁻¹ (120-150cm), while in profile P2 (Hebbal (K)), P3 (Havinal) P4 (ARS, Kawadimatti) and P7 (Devapur. J), it decreased with depth from 112.58 to 82.97, 161.82 to 85.91, 101.82 to 45.57 and 133.82 to 77.80 Kg ha⁻¹, respectively. In profile P5 (Farmer's field, Kawadimatti), it decreased upto fourth depth and showed indefinite trend of distribution in the subsequent depths. In profile P6 (Islampur), definite trend was not observed.

4.3.2 Available phosphorus

Available P in the profiles studied varied between 2.2 and 12.8 kg ha⁻¹. The lowest available P was noticed in the last depth of profile P1 (Hebbal (B)) and in the fourth depth of profile P4 (ARS, Kawadimatti) and the highest, in the second depth of the profile P3 (Havinal). As per the ratings for available P(<10 Kg ha⁻¹, low; 10-25 kg ha⁻¹, medium and > 25 Kg ha⁻¹, high), the profile samples had low to medium amount of available P supply. Profile P1 (Hebbal (B)) and P5 (Farmer's field, Kawadimatti) recorded low to medium amount of available P, which decreased with depth. In these profiles, the decrease in available P content from surface to the last depth was of the order : 9.60 to 2.20 and 12.30 to 5.66 Kg ha⁻¹, respectively. In profile P1 (Hebbal (B)), the depth wise distribution pattern was : 9.60 (0-15 cm), 9.10 (15-30 cm), 7.90 (30-60 cm), 4.46 (60-90 cm), 3.46 (90-120 cm) and 2.20 Kg ha⁻¹ (120-150 cm). Similarly, profiles P4 (ARS, Kawadimatti),

P6 (Islampur) and P7 (Devapur. J) also recorded low amount of available P at all the depths, which decreased upto fourth depth and increased thereafter. However, in profile P2 (Hebbal (K)), from second depth (15-30 cm) onwards, it decreased throughout.

4.3.3 Available Potassium

Available K in the soils ranged between 160.8 and 483.6 Kg ha⁻¹ and according to the ratings (<120 Kg ha⁻¹, low : 120 to 180 Kg ha⁻¹, medium and > 180 Kg ha⁻¹, high), the soils studied possess medium to high amount of this nutrient. The lowest available K was noticed in the fifth depth of profile P6 (Islampur), while the highest, in the surface layer of profile P7 (Devapur. J). Its distribution with the depth in majority of the profiles did not follow a definite trend. However, in profiles P1 (Hebbal (B)) and P5 (Farmer's field, Kawadimatti), it decreased with the depth from 413.4 to 195.0 and 335.4 to 168.8 Kg ha⁻¹, respectively. The sequence of decrease in profile P1 (Hebbal (B)) was : 413.4 (0-15 cm), 327.6 (15-30 cm), 288.6 (30-60 cm), 265.2 (60-90 cm), 210.6 (90-120cm) and 195.0 kg ha⁻¹ (120-150 cm). In profile P7 ((Devapur. J) also it decreased upto fifth depth. whereas, in profiles P2 (Hebbal (K)) and P6 (Islampur), it decreased upto third depth and showed an indefinite trend of distribution in the subsequent depths.

Table 8 - Major nutrients status of soil

Profile No	Location	Depth (cm)	Available-N -----	Available-P (kg ha ⁻¹)-----	Available-K -----
P1	Hebbal(B)	0-15	142.70	9.60	413.4
		15-30	124.02	9.10	327.6
		30-60	110.80	7.90	288.6
		60-90	92.13	4.46	265.2
		90-120	84.02	3.46	210.6
		120-150	80.91	2.20	195.0
P2	Hebbal(K)	0-15	112.58	10.10	405.6
		15-30	108.70	10.10	241.8
		30-60	96.36	8.86	163.8
		60-90	93.47	6.90	327.6
		90-120	87.14	5.66	265.2
		120-150	82.97	3.46	288.6
P3	Havinal	0-15	161.82	11.10	374.4
		15-30	133.82	12.80	187.2
		30-60	103.48	7.12	195.0
		60-90	96.47	8.16	249.6
		90-120	93.36	5.38	335.4
		120-150	85.91	4.70	280.8
P4	ARS,Kawadi- -matti	0-15	101.82	5.66	356.0
		15-30	95.12	3.96	202.8
		30-60	80.91	3.70	218.4
		60-90	71.58	2.20	273.0
		90-120	65.35	6.60	226.2
		120-150	45.57	7.40	265.2
P5	Farmer's field kawadimatti	0-15	96.47	12.30	335.4
		15-30	71.58	9.36	304.2
		30-60	65.35	8.60	280.8
		60-90	59.13	7.90	241.8
		90-120	60.79	6.40	210.6
		120-150	49.79	5.66	168.8
P6	Islampur	0-15	138.37	6.40	413.4
		15-30	121.39	5.66	390.0
		30-60	96.47	4.46	319.8
		60-90	93.36	3.96	397.8
		90-120	96.42	8.40	160.8
		120-150	90.29	8.56	210.6
P7	Devapur.J	0-15	133.82	7.40	483.6
		15-30	108.92	6.40	319.8
		30-60	99.58	5.90	304.2
		60-90	87.14	4.36	241.8
		90-120	84.02	7.89	210.6
		120-150	77.80	9.60	312.0

4.3.2 Micronutrient status of soils (Table 9).

4.3.2.1 DTPA - extractable Zn

DTPA Zn in the soils ranged between 0.22 and 0.67 ppm. The lowest DTPA Zn content was recorded in the last depth of profile P2 (Hebbal (K)), while the highest, in profile P6 (Islampur, 15-30 cm). As per the ratings (< 0.6 ppm, deficient and > 0.6 ppm, sufficient), more than fifty per cent profile soil samples contained low DTPA Zn and its content generally decreased with depth. In profile P1 (Hebbal (B)), the trend of decrease with the depth was : 0.60 (0-15 cm), 0.46 (15-30cm), 0.40 (30-60 cm), 0.34 (60-90 cm), 0.31 (90-120 cm) and 0.30 ppm (120-150 cm). In profile P2 (Hebbal (K)), P3 (Havinal), P5 (Farmer's field, Kawadimatti) and P7 (Devapur. J), it decreased with the depth from 0.42 to 0.22, 0.51 to 0.25, 0.45 to 0.24 and 0.60 to 0.37 ppm, respectively. In remaining profiles, the trend was not definite.

4.3.2.2 DTPA - extractable Cu

DTPA Cu in the soils varied between 0.22 and 2.16 ppm. The lowest value was recorded in the last depth of profile P4 (ARS, Kawadimatti), while the highest, in the surface layer of profile P6 (Islampur). All these soils contain medium to adequate quantity of DTPA - Cu as per the ratings (<0.2 ppm, deficient and > 0.2 ppm, sufficient). In general, DTPA-Cu was more in surface than subsurface depths in majority of the profiles. In profile P2 (Hebbal (K)), the sequence of decrease with the depth was: 0.96 (0-15 cm), 0.81 (15-30cm),

0.78 (30-60 cm) 0.69 (60-90 cm), 0.61 (90-120 cm) and 0.40 ppm (120-150 cm). In profiles P2 (ARS, Kawadimatti) and P7 (Devapur. J), it decreased with the depth from 1.30 to 0.22 and 1.52 to 0.68 ppm, respectively. In profile P5 (Farmer's field, Kawadimatti), it decreased upto fifth depth, whereas, in profiles P1 (Hebbal (B)) and P3 (Havinal), it decreased upto third depth, showing an and indefinite trend of distribution in the subsequent depths. In remaining profiles, the trend was not definite.

4.3.2.3 DTPA extractable Mn

DTPA-Mn in the soils ranged between 6.10 and 13.45 ppm. The lowest DTPA-Mn content was recorded in the last depth of profile P2 (Hebbal (K)), whereas the highest, in the surface layer of profile P3 (Havinal). All the soils recorded adequate quantity of DTPA-Mn as per the ratings (< 2.00 ppm, deficient and > 2.00 ppm, sufficient). In majority of profiles studied, DTPA-Mn decreased with depth. In profile P2 (Hebbal (K)), the order of decrease with the depth was : 8.13 (0-15 cm), 7.91 (15-30cm), 7.14 (30-60 cm), 6.80 (60-90 cm), 6.12 (90-120 cm) and 6.10 ppm (120-150 cm), while in profiles P3 (Havinal), P4 (ARS, Kawadimatti), P6 (Islampur) and P7 (Devapur.J), it decreased with the depth from 13.45 to 10.13, 9.18 to 7.31, 8.31 to 6.81 and 9.17 to 7.61 ppm, respectively. In rest of the profiles, the trend was not definite.

Table 9 - DTPA-extractable micronutrient status of soils

Profile No	Location	Depth (cm)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)
P1	Hebbal(B)	0-15	0.60	1.64	9.36	6.58
		15-30	0.46	0.92	8.91	6.10
		30-60	0.40	0.64	8.53	5.66
		60-90	0.34	0.88	8.91	4.50
		90-120	0.31	0.64	7.20	2.44
		120-150	0.30	0.86	7.52	4.22
P2	Hebbal(K)	0-15	0.42	0.96	8.13	8.93
		15-30	0.39	0.81	7.91	7.26
		30-60	0.36	0.78	7.14	5.15
		60-90	0.29	0.69	6.80	5.61
		90-120	0.23	0.61	6.12	4.70
		120-150	0.22	0.40	6.10	6.98
P3	Havinal	0-15	0.51	0.80	13.45	7.39
		15-30	0.48	0.75	12.91	6.77
		30-60	0.36	0.70	12.15	6.21
		60-90	0.31	0.71	12.06	5.76
		90-120	0.29	0.63	11.51	4.50
		120-150	0.25	0.62	10.13	4.22
P4	ARS, Kawadi-matti	0-15	0.46	1.30	9.18	8.71
		15-30	0.60	0.92	8.65	7.02
		30-60	0.36	0.78	7.81	6.61
		60-90	0.26	0.63	7.60	5.96
		90-120	0.30	0.41	7.21	5.66
		120-150	0.33	0.22	7.31	5.21
P5	Farmer's field, kawadimatti	0-15	0.45	1.26	10.81	12.17
		15-30	0.44	0.90	10.63	11.06
		30-60	0.34	0.80	9.16	9.50
		60-90	0.32	0.62	10.32	6.40
		90-120	0.26	0.30	9.53	5.15
		120-150	0.24	0.30	9.69	5.15
P6	Islampur	0-15	0.36	2.16	8.31	5.95
		15-30	0.67	1.60	8.12	5.90
		30-60	0.63	1.16	7.86	4.61
		60-90	0.31	1.46	7.12	4.50
		90-120	0.30	1.32	7.10	6.46
		120-150	0.31	1.58	6.81	4.22
P7	Devapur.J	0-15	0.60	1.52	9.17	6.96
		15-30	0.53	0.96	9.03	6.77
		30-60	0.52	0.94	8.61	6.46
		60-90	0.42	0.81	8.11	5.76
		90-120	0.40	0.73	7.83	4.50
		120-150	0.37	0.68	7.61	3.49

4.3.2.4 DTPA - extractable Fe

DTPA Fe in the soils varied between 2.44 and 12.17 ppm. The lowest DTPA - Fe was recorded in the fifth depth of profile P1 (Hebbal (B)) and the highest value, in the surface layer of profile P5 (Farmer's field, Kawadimatti). All these soils recorded marginally deficient to sufficient DTPA-Fe (< 4.00 ppm, deficient and > 4.00 ppm, sufficient) and in majority of the profiles, DTPA Fe decreased with the depth. In profile P3 (Havinal) the sequence of decrease with the depth was : 7.39 (0-15 cm), 6.77 (15-30cm), 6.21 (30-60 cm), 5.76 (60-90 cm), 4.50 (90-120 cm), 4.22 ppm (120-150 cm). Whereas in profiles P4 (ARS, Kawadimatti), P5 (Farmer's field, Kawadimatti) and P7 (Devapur. J), it decreased with the depth from 8.71 to 5.21, 12.17 to 5.15 and 6.96 to 3.49 ppm, respectively. In profile P1 (Hebbal (B)), it decreased upto fifth depth, while, in profiles P2 (Hebbal (K)) and P6 (Islampur), it decreased upto third or fourth depth, showing an indefinite trend of distribution in the subsequent depths. In other profiles, no definite trend could be made out in this regard.

DISCUSSION

V. DISCUSSION

In an attempt to feed the burgeoning population of our nation, by way of achieving self-sufficiency in food production, more and more area of the arid and semi-arid regions is being brought under irrigation network. Though this move, for the most part, has proved to be a blessing by ushering in an era of "Green Revolution", of late, the problems arising out of soil salinization and/or sodiumization are threatening to impede the benefits of irrigation facilities.

Area under salt-affected soils, is increasing with every passing year, both in India and at global scale, vary in their behaviour for crop production in several ways through changes in physical, chemical and biological properties. These changes have a bearing on the crop production.

Keeping these aspects in view, the present investigation was carried out and the results of the same have been discussed in this chapter under the following headings :

1. Physical properties
2. Chemical properties and
3. Nutrient status of salt-affected soils of Upper Krishna Project Area, Karnataka.

5.1 Physical properties of soils

5.1.1 Bulk density (BD)

In the soils studied, BD, which generally registered an increase with profile depth, varied between 1.38 and 1.60 Mg m⁻³. Higher BD values in these soils may be attributed to dispersion of clay particles upon saturation with sodium and consequent clogging of pores, resulting in reduced porosity. Results similar to these have been reported earlier by Bouma and Hole (1971) and Pandey and Pathak (1975).

The increase in BD values with the depth in soil may be ascribed to increased clay content at lower depths and it may be due to sharp decrease in organic carbon from top depths to lower layers. The latter inference may be attested to by the fact that a significant negative correlation ($r=-0.60^{**}$) was evident between organic carbon and BD. These results find support from the findings of Doddamani *et al.* (1994), who observed increased BD at lower depths of black cotton soils of Karnataka.

5.1.2 Particle density (PD)

The soils had PD values ranging between 2.54 and 2.78 Mg m⁻³. The values did not vary markedly both within and between the profiles, conforming to the asserted fact that the PD is a basic soil property which does not vary much with variation in type and amount of salinity (Pandey and Pathak, 1975).

5.1.3 Porosity

With its values ranging from 38.58 to 47.81 per cent, porosity generally exhibited a decrease with increasing depths in soil profiles investigated. The trend may be attributed to increase in dispersible clay content with the depth in majority of the soils studied. As in case of BD, these clay particles dispersed due to high ESP, clog the pore spaces and bring about a reduction in porosity (Mathan and Mahendran, 1994).

5.1.4 Maximum water holding capacity (MWHC)

The values of MWHC ranged between 40.12 and 73.21 per cent and in most of the profiles investigated, increased upto third or fourth depth, showing a decrease thereafter. An increase in MWHC might be due to increase in clay content, since the former and soil texture are directly related (Ghildyal and Satyanarayana, 1965). The MWHC values had significantly positive correlation with clay content ($r=0.83^{**}$), suggesting that as the texture becomes finer and as the sodicity increases, MWHC also increases.

5.1.5 Volume expansion (VE)

Soils investigated had VE values varying between 34.69 and 47.08 per cent, exhibiting a similar trend as that of MWHC. The increase in VE with the depth may be ascribed to increase in clay content, as indicated by positive and

correlation obtained between volume expansion and $r=0.80^{**}$). The results conform to the observation rubur (1989) in the Vertisols of north Karnataka.

e size distribution

A persual of the data presented in Table 2 reveals that one, soils are clayey in texture. The sand in the soils (16.71 to 38.50 per cent) exhibited a decrease upto third or fourth depth and increased in most of the profiles studied. A sudden increase in sand coupled with a simultaneous decrease in clay in lower layers of the profiles may be attributed to the presence of a buried profile (Sahu et al., 1986).

The increase of sand fraction at the bottom or in plough layer was also noticed by Asnakew Woldeab (1988) in Vertisols of sub-Saharan Africa.

The distribution of silt fraction, which varied from 31.42 per cent in the soils investigated, was, in general, consistent with depth. However, in profiles P2 and P7 (Devapur (J)) a specific trend of increase in silt upto third or fourth depth was evident, which might be due to the transportation of silt to lower layers through erosion associated with leaching phenomenon (Goel and Singh, 1986).

The quantity of clay in the soils was more than 40 per cent in lower depth of profiles P2, which recorded

clay content of 38.32 per cent. The increase in clay content with the depth may be because of its illuviation to lower depths (Krishnamoorthy and Govindarajan, 1977). Further, percolating water as well as salt content of these soils might have played key role in the movement of finer sized particles to the underlying layers. The latter inference stems from the fact that all the soils, as revealed by chemical analysis (Table 5), are affected by sodicity of various degrees. The process of sodification of surface soils might have led to dispersion and consequently, migration of dispersed clay particles might have occurred to lower depths with the percolating water (Dubey *et al.*, 1984).

5.2 Chemical properties

5.2.1 Soil reaction

An alkaline reaction was evident in the soils investigated in the study and in the majority of the soils, pH recorded was more than 8.0 but less than 8.5. However, in some profiles - (P2 (Hebbal(K)), P4 (ARS, Kawadimatti) and P7 (Devapur.J)) - soil pH was more than 8.5, particularly at subsurface depths, which may be attributed to higher ESP values associated with these depths and relatively higher quantity of carbonates. The results corroborate with the finding of Cruz-Romero and Coleman (1975), who inferred that the exchangeable Na and CaCO_3 react in low CO_2 and low salt system to produce high pH and appreciable concentration of Na_2CO_3 .

Soil pH has increased with the depth in most of the profiles studied. This may be because, with the depth, the salt content has generally decreased (Table-4), while ESP has increased. As the salt content decreases, dehydroxylation of Al - complex increases, leading to production of more Al^{3+} ions on clay surface which, in turn, causes more Na^+ ions to hydrolyze into solution, causing an increase in soil pH (Kamil and Shainberg, 1968). Since EC showed a negative correlation with water soluble Na^+ and since the latter generally increased with the depths (Table 6), similar inference can be drawn for the soils under study.

5.2.2 Electrical conductivity

In all the soil profiles, accumulation of salts was found at surface and as per the definition of U.S.S.L Staff (1954), these soils were mostly saline ($EC > 4.0 \text{ dS m}^{-1}$). The decreasing trend in EC of the soils with the depth may be attributed to shallow water table (Appendix) and intensive evaporation during pre-monsoon period. Findings similar to these have also been made by many earlier workers (Mediratta *et al.*, 1985 ; More *et al.*, 1988).

5.2.3 Organic carbon

Organic carbon content in the soils ranged between 0.09 and 0.63 per cent and it generally decreased with the depth. The lower organic carbon content in these soils may be attributed to prevalence of high temperature in the

region during most part of the year, which brings about the oxidation of organic matter at a rapid rate. The higher accumulation of organic carbon in the surface layer compared to subsurface layer is because, the residues of the crops every year get accumulated in surface layers without substantial movement downwards. Similar observations have been made by More *et al.* (1988) in the salt-affected soils of Purna Command Area of Maharashtra and also by Mediratta *et al.* (1985) in the salt-affected soils of Harsi Command Area of Madhya Pradesh.

5.2.4 Cation exchange capacity

Soils had CEC values varying between 32.19 and 59.16 c mol (p^+) kg^{-1} and values, in general, increased upto third or fourth depth, showing a decrease thereafter. The higher CEC may be on account of dominance of montmorillonitic type of clay in these soils (Nalatwadmath, 1985), which has its 70 to 90 per cent of charge density located in the tetrahedral layer, causing an increase of CEC. The increase of CEC with the depth might be owing to increase of clay content with the depth. The latter observation is attested to by the fact that the CEC and clay showed a significantly positive correlation ($r=0.71^{**}$). Similar trend of CEC with depth has been also reported in salt-affected Vertisols of Ghataprabha Left Bank Area (Katti and Rao, 1979) and Bijapur district (Ballolli, 1987) of Karnataka.

Doddamani *et al.* (1994), in a study on physico-chemical properties of some soils occurring in the Upper Krishna Project Area (Karnataka) also opined that the higher CEC values would be indicative of dominance of smectite group of clay minerals in the soils.

5.2.5.1 Exchangeable cations

Calcium and magnesium together formed the major portion of exchangeable cations in the soils studied and ranged between 24.0 and 46.8 c mol(p⁺) kg⁻¹. As indicated by a significantly positive correlation between clay content and exchangeable Ca²⁺ + Mg²⁺ (r=0.67^{**}), the higher proportion of latter was on account of higher clay content (smectite group) in the soils. In general, exchangeable Ca²⁺ + Mg²⁺ increased with the profile depth, which was again because of increase in clay fraction with the depth. Though exchangeable Ca²⁺ + Mg²⁺ content increased towards the lower depths, the increase was not marked and, on the whole, the variation in an individual soil body remained within 10 c mol(p⁺) kg⁻¹. Similar observations were also made by Doddamani *et al.* (1994). The next dominant cation in the soils was Na⁺ (1.74 to 14.11 c mol(p⁺) kg⁻¹) and its depth-wise distribution trend almost coincided with that of exchangeable Ca²⁺ and Mg²⁺. As supported by positive and significant association between exchangeable Na⁺ and clay content (r=0.69^{**}), increasing trend of Na⁺ may be attributed to increased clay fraction at lower depths. The results find support from the findings of

Krishnamoorthy and Govindarajan (1977) and Roy et al. (1962) in Vertisols of Andhra Pradesh and Karnataka, respectively. Exchangeable K^+ in the soil was in the range of 0.15 to 0.62 c mol(p⁺) kg⁻¹ and, with its distribution trend being generally irregular in the soil profiles, it formed relatively lower portion of soil CEC. Dhillon et al (1985), while working with some benchmark soils of north west India, felt that the inconsistent distribution of exchangeable K^+ in the soils results because, this form of K^+ is mainly controlled by amount of clay and weathering conditions, factors which are not consistent with depth of soil profiles.

5.2.5.2 Exchangeable sodium percentage

Profile P2 (Hebbal (K)), P4 (ARS, Kawadimatti) and P7 (Devapur.J) recorded an ESP of more than 15.0 throughout their depths, while in others only few depths recorded ESP values > 15.0. The trend of ESP to increase with profile depth may be attributed to the effect of fluctuation due to shallow water table (Appendix). The results are in consonance with the findings of Kanwar and Sehgal (1962) who also found a similar pattern in salt - affected soils of Kangra district of Himachal Pradesh.

5.2.6.1 Water soluble cations

Water soluble Na^+ , which showed diverse trends of depth wise distribution in soil profiles, dominated the soil solution cationic composition over other cations. Such varying

trends of water soluble Na^+ have also been reported in salt-affected soils of Ghataprabha Left Bank Canal Area (Katti and Rao, 1979), and in Purna Command Area of Maharashtra (More *et al.*, 1988). This could be because Na-salts are mobile and move to lower depths after irrigation and under dry spell move upward due to capillary rise of water and accumulate in surface layers. As regards its content, it was in the range of 8.25 to 33.42 me L^{-1} compared to lower concentration of $\text{Ca}^{2+} + \text{Mg}^{2+}$ 2.0 to 32.0 me L^{-1}) in the soil solution. A higher concentration of former in salt-affected soils, with high pH, has also been reported by More *et al.* (1988).

Water soluble K^+ formed a smaller fraction of cationic composition of soil solution and varied extensively between 0.005 and 0.154 me L^{-1} . Though it appears to be a smaller quantity, it is relatively higher compared to that in normal soils, which may be because of dissolution of K-bearing minerals such as feldspars and micas in sand and clay fractions of the soils. Relatively larger water soluble K^+ was observed in poorly drained soils of Saudi Arabia by Viani *et al.* (1983), and Pal and Mandal (1980) observed a higher release of K^+ in presence of NaCl than that of CaCl_2 or ammonium acetate. Since the soils under study also contain higher quantities of water soluble Na^+ , similar inference can be made for these also.

5.2.6.2 Water soluble anions

Chlorides (6.5 to 34.5 me L⁻¹), were the most dominant of water soluble anions, followed by sulphates (3.0 to 30.9 me L⁻¹) and bicarbonates (1.4 to 6.4 me L⁻¹), while carbonates were found generally in traces. The composition of soluble salts is greatly influenced by hydrochemical zonality. When rainfall of about 750 mm is received annually, CO₃⁻² and HCO₃⁻¹ are the dominant anions followed by chlorides and sulphates, around isohyets of 500-550 mm mixed anionic composition with SO₄-CO₃-Cl are common. Below the 300 mm isohyete Cl and SO₄ dominated with clay traces of CO₃ (Bhargava *et al.*, 1980). Since the soil bodies investigated lie in arid region, the dominance of chlorides and sulphates is expected.

5.2.6.3 ESP-SAR relationship (Table 4 and 5 and fig.2)

In order to obviate the necessity of determining exchangeable cations which is laborious and sometimes leads to errors, attempts are being made to arrive at ESP values of soils by measurement of SAR. The equation developed by U.S.S.L. Staff (1954) has been useful in predicting the ESP values from a knowledge of cationic composition of soil water extracts. However, the disagreement between predicted ESP and actual ESP have been widely reported (El-Seewier *et al.*, 1977 ; Bhadrapur and Rao, 1977). An attempt was, therefore, made to verify the adaptability of the said equation to predict ESP in the soils taken for study.

A persual of the data presented in Tables 4 and 5 and the figure 2, reveals that the agreement between actual and predicted ESP values was rather very poor, with the determined (actual) ESP values being generally very much higher than predicted values. This means a gross underestimation of sodicity hazard which is undesirable and has disastrous consequences in handling these soils for reclamation and management. Though there was positively significant association ($r=0.96^{**}$) between predicted ESP and actual ESP, it appears that the U.S.S.L. Staff equation cannot be used in practical prediction of sodicity hazard of the soils studied because individually, the relationship between the two is very poor.

5.3 Nutrient status of salt-affected soils.

5.3.1 Available Nitrogen

Soils investigated had very low nitrogen availability (45.57 to 161.82 kg ha⁻¹), considering the critical limits (< 280, 280-560 and >560 kg ha⁻¹ as low, medium and high respectively) proposed by Muhr *et al.*, (1963). The lower values of N availability might be on account of poor physical conditions of the soils (Table 2), which might have accentuated the losses of soil N due to denitrification and volatilization. The alkaline pH of the soils and extremely arid conditions of the area, i.e., low rainfall accompanied by strong drying conditions, might have caused appreciable volatilization losses of N in the soils (Jenny and Raychaudhuri, 1960). It may be also because of lower

nitrification levels, since threshold level of pH for the process to occur at an optimal pace is around 7.7 to 7.8 (Martin et al., 1943). Also since the soils investigated in this study are fine textured and sodiumized, reduction in N-fixation by microorganisms, whose activity is limited due to reduced energy source caused by reduction in the growth of host plants, may also be quoted as a possible reason for reduced N availability in these soils (Bhardwaj, 1975).

The surface layers of all the profiles contained higher quantities of available N and it invariably reduced down the profile. Since a positive relationship has been observed between organic carbon and alkaline permanganate mineralizable N ($r=0.36^{**}$), lower values of organic carbon at lower depths, coupled with lower activity of microbes therein, may be responsible for decrease in available N with the depth.

These results indicate the need for extra additions of N to these soils for improved crop performance. However, since the losses due to volatilization and denitrification are sure to occur under the conditions stated, methods which increase efficiency of applied N must be adopted, and one of them appears to be green manuring with crops like *Sesbania* Spp which perform comparatively well under sodic soil (Singh, 1989).

5.3.2 Available Phosphorus

Contrary to the usual inference that the salt affected soils, particularly the sodic soils, contain higher amounts of Olsen's extractable P (Chhabra *et al.*, 1981), the soils investigated contained lower amounts of available P (2.2 to 12.8 kg ha⁻¹), particularly at second depth downwards. The decreased availability of P in the soil may be because of precipitation of P as insoluble Ca-Phosphates, since the soils are calcareous and have a very high pH (Anonymous, 1993a). Higher amounts of available P in surface layers and a drastic reduction at lower depths are to be expected because of immobile nature of this element in the soils. This is particularly so in soils studied, wherein the downward movement of P applied in surface layers is severely hampered due to higher clay content and poor drainage conditions.

5.3.3 Available potassium

Considering the critical limit proposed for the region (Muhr *et al.*, 1963), soils appeared to be medium to higher in amount of available K, which varied between 160.8 and 483.6 kg ha⁻¹. This explains the poor response of the crops in the region to K fertilizer application. Although in majority of the profiles, its distribution with depth was inconsistent. In profiles P1 (Hebbal (B)), P5 (Farmer's field, Kawadimatti) and P7 (Devapur.J), generally available potassium decreased with depth. Increase in SAR and accumulation of exchangeable Na at

lower depths might have reduced the mobility of this nutrient to downward layers (Chhabra, 1985). The inference drawn is further supported by the fact that sodicity hazard, as measured by ESP and SAR, showed a negative, though not significant, association with available K.

5.3.4 DTPA - extractable micronutrients.

5.3.4.1 DTPA - extractable Zinc

In the soils studied, the DTPA - Zn was in the range of 0.22 to 0.67 ppm and mostly surface layers contained higher amount of this nutrient. Considering the critical limit of 0.6 ppm, these soils were low in DTPA Zn. In normal soils, pH has been stated to be governing factor in Zn availability, while in soils affected with sodicity ESP is the key factor (Shaw and Dean, 1952 ; Singh et al., 1983). The relation is such that as the soil pH increases, DTPA-extractable Zn decreases and on the other hand, increase in sodicity is thought to increase its availability. However, neither of these phenomenon appears to be operating in the soils studied because soil pH, though showed a negative relation with DTPA-Zn, was not significant and ESP was positively but nonsignificantly correlated with the former. The higher Zn availability in surface layers and its decreasing trend down the profile may be ascribed to decrease in organic carbon content and increase in soil pH with the depth. Joshi et al., (1983) also recorded a decrease in Zn availability with increase in pH and decrease in organic carbon.

5.3.4.2 DTPA extractable copper, manganese and iron

Soils contained medium to adequate quantities of DTPA-Cu (0.22 to 2.16 ppm), low to sufficient amounts of DTPA-Fe (2.44 to 12.17 ppm) and extremely higher amounts of DTPA-Mn (6.10 TO 13.45 ppm). The reduction in availability of all these nutrients with depth may be ascribed to decrease in organic carbon, increase in CaCO_3 (Appendix), increase in soil pH (Table 3) and clay content with the depth. The positive and significant correlation between DTPA-Cu and organic carbon ($r=0.56^{**}$) may be attributed to the formation of stable complexes with natural complexing agents in soil solution. Because of this reason, Cu deficiency is not as prevalent as that of Zn, even though both the cations show similar changes in solubility with changing pH (Arora and Sekhon, 1981). significant and negative correlation between DTPA - Fe and pH ($r=-0.36^*$) may be due to the fact that Fe-DTPA is unstable at pH above 7.0 where Ca^{2+} successfully displaces Fe^{3+} . Moreover, Fe-DTPA is less stable because of partial breakdown of DTPA ligand (Norvell, 1972). Since there was no significant correlation observed between DTPA - Fe and organic carbon ($r=0.22$), the former might have originated from inorganic phase. Similarly, negatively highly significant correlation of DTPA-Mn with soil pH ($r=-0.45^{**}$) also points at the inorganic phase as the main source of DTPA extractable Mn.

Table 10 - Correlation matrix for soil physico - chemical properties

	EC	OC	CEC	Ca+Mg	Na	ESP	W.S. Na	SAR	P.ESP	Avail 'N'	Avail 'p'	Avail 'K'	Zn	DTPA	Cu	Mn	DTPA	Fe	BD	Porosity	WHC	VE	Clay
1 pH	-0.835	-0.215	0.455	0.311	0.608	0.623	0.407	0.585	0.559	0.548	0.370	-0.202	-0.252	-0.459	-0.451	-0.359	0.469	0.433	0.541	0.250	0.415		
2 EC		0.135	-0.375	-0.453	-0.597	-0.613	-0.375	-0.647	-0.820	0.422	0.328	0.271	0.152	0.418	0.481	0.377	-0.464	0.277	-0.564	-0.451	-0.559		
3 OC			-0.075	-0.184	0.220	0.213	0.375	0.324	0.304	0.361	0.157	0.603	0.760	0.564	-0.047	0.221	-0.594	0.394	-0.151	0.034	-0.031		
4 CEC				-0.962	0.829	0.828	0.285	0.528	0.571	-0.073	-0.241	-0.217	-0.089	-0.137	-0.362	-0.184	0.187	0.017	0.875	0.478	0.712		
5 Ca+Mg					0.664	0.432	0.109	0.325	0.367	-0.104	-0.207	-0.254	-0.144	-0.115	-0.325	-0.211	0.304	-0.008	0.597	0.451	0.668		
6 Na						0.927	0.536	0.871	0.881	-0.064	-0.308	-0.170	0.028	-0.140	-0.343	-0.019	0.133	0.041	0.739	0.437	0.686		
7 ESP							0.858	0.938	0.961	-0.140	-0.234	-0.030	0.118	-0.084	-0.258	0.029	0.119	-0.363	0.871	0.444	0.628		
8 W.S.Na								0.704	0.887	-0.072	-0.229	0.150	0.186	0.033	-0.219	-0.023	-0.139	0.079	0.294	0.287	0.342		
9 SAR									0.982	-0.075	-0.383	-0.064	0.088	-0.123	-0.309	0.007	-0.027	0.073	0.810	0.355	0.549		
10 P.ESP										-0.070	-0.322	-0.044	0.088	-0.125	-0.288	0.008	-0.023	0.075	0.824	0.383	0.579		
11 Avail 'N'											0.397	0.513	0.585	0.557	0.527	0.178	-0.688	0.756	-0.018	0.389	0.129		
12 Avail 'p'												0.120	0.247	0.121	0.442	0.472	-0.453	0.464	-0.214	-0.011	-0.165		
13 Avail 'K'													0.463	0.553	0.080	0.281	-0.466	0.485	-0.133	0.107	-0.017		
14 DTPA-Zn														0.509	0.228	0.308	-0.527	0.461	0.009	0.093	0.036		
15 DTPA-Cu															-0.053	0.174	-0.411	0.543	-0.095	0.180	0.045		
16 DTPA-Mn																0.360	-0.486	0.280	-0.107	-0.080	-0.056		
17 DTPA-Fe																	-0.355	0.301	-0.194	-0.319	-0.154		
18 BD																		-0.952	0.331	-0.202	0.112		
19 Porosity																			-0.176	0.442	0.149		
20 WHC																				0.529	0.831		
21 VE																						0.800	
22 Clay																							

* Significant at 5 per cent

** Significant at 1 per cent

SUMMARY

VI . SUMMARY

Reclamation and management of salt - affected soils is of extreme importance, keeping in view the faster rate at which land accessible for agricultural use is diminishing. Reclamation and management technologies vary from one region to another, since salt-affected soils of different areas show wide variations among themselves, depending upon parent material, topography, climate, hydrology and land use pattern. Therefore, technologies developed for salt-affected soils of Indo-Gangetic alluvial plains may not be applicable for those occurring in peninsular region of India. Successful management of salt-affected soils includes, in addition to reclamation measures, nutrient management as an important component, for which an understanding of the nutritional status of these soils is of primary importance. Keeping these aspects in view and considering the fact that in this regard not much information is available, present study was taken up to characterize, classify and delineate nutrient status of some salt-affected Vertisols of Upper Krishna Project Area, Karnataka. For the investigation, seven profiles, representing large area of the command area, were selected. The soil samples were analysed for various parameters in accordance with objectives of the study and results of the same are summarized as follows.

1. The soils studied were clayey in texture, except in profile P2 (Hebbal (K)), wherein at last depth soil was clay loam in texture.
2. The soils had higher bulk density values ranging between 1.38 and 1.60 Mg m⁻³ and the values increased with the profile depth. On the other hand, the soil porosity decreased with the depth and varied from 38.58 to 47.81 per cent.
3. Maximum water holding capacity varied from 40.12 to 73.21 per cent and increased upto third or fourth depth, registering a decrease at further depths. Volume expansion of the soils, which also showed a similar trend, ranged between 34.69 and 47.08 per cent. Both these physical parameters had significantly positive correlations with clay content in the soils ($r=0.83^{**}$ and $r=0.79^{**}$, respectively).
4. An alkaline reaction was recorded in all the soils and pH values, which registered an invariable increase down the soil profiles, varied mostly between 7.50 and 9.10. Soil pH values of more than 8.50 were met with, however, in profiles P2 (Hebbal (K)), P4 (ARS, Kawadimatti) and P7 (Devapur.J).
5. Electrical conductivity values decreased with the profile depth and varied from 1.0 to 6.4 dSm⁻¹.
6. Cation exchange capacity (CEC) of the soils investigated was high and, showing a variation between 32.19 and 59.16 c mol (p⁺) kg⁻¹, generally it increased upto fourth depth and reduced at further layers.

7. Among exchangeable cations, $\text{Ca}^{2+} + \text{Mg}^{2+}$ formed the major fraction of CEC and, with a general tendency to increase down the profile layers, varied between 24.0 and 46.8 c mol (p^+) kg^{-1} . With its depth wise distribution trend generally coinciding with that of exchangeable $\text{Ca}^{2+} + \text{Mg}^{2+}$. Exchangeable Na^+ was the next dominant contributor to soil CEC and its values ranged from 3.04 to 14.11 c mol(p^+) kg^{-1} . Exchangeable K^+ formed comparatively smaller fraction of soil CEC and, showing an inconsistent distribution trend, was in the range of 0.15 to 0.62 c mol (p^+) kg^{-1} .
8. Salinity alone was noticed in the profiles P1 (Hebbal (B)) and P5 (Farmer's field, Kawadimatti), while in all other soil bodies investigated, generally salinity alone or salinity-cum-sodicity was recorded at top one or two depths, with lower layers being sodic in nature.
9. In soil solution, cationic composition was dominated by Na^+ (8.25 to 33.42 meL^{-1}), followed by $\text{Ca}^{2+} + \text{Mg}^{2+}$ (2.0 to 32.0 me L^{-1}), while concentration of K^+ in soil solution was relatively low.
10. Salinity observed in the soils was of chloride type and the concentration of water soluble chloride (6.5 to 34.5 me me L^{-1}) was followed by sulphates (3.0 to 30.9 me L^{-1}) and bicarbonates (1.4 to 6.4 me L^{-1}), while carbonates were present in trace quantities.
11. Adoption of U.S.S.L. Staff equation to arrive at soil ESP values did not appear to suit the soils studied, despite significantly positive correlation between predicted and actual ESP.

12. The soils studied were low in available N supply which, showing an invariable decrease down the profile layers, varied between 45.57 and 161.82 kg ha⁻¹.
13. The soils were also mostly low in P availability. The Olsen's P values ranged from 2.2 to 12.8 kg ha⁻¹ and in general, decreased as the profile depth increased.
14. On the contrary, the soils were mostly medium to higher in K supply. Its depth wise distribution trend being generally irregular, K availability in the soils was in the range of 160.8 to 483.6 kg ha⁻¹.
15. DTPA - Zn in the soils ranged between 0.22 and 0.67 ppm and did not show a definite relationship with soil reaction.
16. Considering the critical limit of 0.2 ppm, DTPA - Cu in the soils varied from medium to high (0.2 to 2.16 ppm) and showed significantly positive correlation with organic carbon ($r=0.56^{**}$).
17. DTPA - Fe content varied extensively from 2.44 to 12.17 ppm, showing a significantly negative correlation with soil pH ($r=0.36^{**}$) and
18. With regard to DTPA - Mn, soils studied were well supplied and with a variation between 6.10 and 13.45 ppm, it also had a significantly negative correlation with soil reaction ($r=0.45^{**}$). In general, concentration of the micronutrients studied decreased with depth.

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APPENDIX

APPENDIX

APPENDIX - I (a)

Details of soil sampling sites :

Profiles : P1 to P5

Location : Hebbal (B) - P1 / Hebbal (K) -P2 / Havinal -P3
A.R.S Kawadimatti -P4/ Farmer's field,
Kawadimatti - P5

Climate : Arid

Parent material : Granite gneiss

Soil order : Vertisols

Sub - order : Usterts

Series : Tumkur series - a member of fine,
montmorillonitic, isohyperthermic family of
Typic Chromusterts.

Competing series: The soils of Kagalgomb series which are derived
from limestone are similar to these soils.

Topography : Nearly level to gently sloping (1.3 % slope)

Drainage : Imperfectly to poorly drained.

Vegetation : Neem, Accacia and Banni

Permeability : Moderately slow to very slow

Land use : Presently cultivated, main crops are cotton and
rabi sorghum.

Distribution : Soils occur in Shorapur taluk of Gulbarga
district and occupy 29.62 % of command area in
the taluk.

Typifying pedon : Tumkur clay - cultivated

Horizon	Depth in cm	Description
Ap	0 - 20	Dark gray (10 YR 4/1) dry, dark grayish brown (10 YR 4/2) moist ; clay; moderate medium, subangular blocky; dry slightly hard, moist firm; wet sticky and plastic; strongly calcareous; few, fine roots; moderately slow permeability pH 8.6 clear smooth boundary.
A1 ₁	20 - 39	Dark grayish brown (10 YR 3/2) moist; clay; moderate, medium, subangular blocky, moist-firm, wet very sticky and plastic ; prominent intersecting slickensides with shining interped faces; strongly calcareous; slow permeability pH 8.8; clear smooth boundary.
A1 ₂	39 - 91	Dark grayish brown (10 YR 4/2) moist; clay moderate, coarse, subangular blocky; moist firm, wet very sticky and very plastic ; prominent slickensides with shining interped faces; strongly calcareous; very slow permeability; pH 8.5; clear smooth boundary.
C	91+	Parent material of granitic origin coated with lime.

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ವಿಶ್ವವಿದ್ಯಾನಿಲಯ ಗ್ರಂಥಾಲಯ
ಗಾ.ಕೃ.ವಿ.ಆರ್., ಬೆಂಗಳೂರು-65

27 MAY 1997

ಅನುವೃದ್ಧಿ ಸಂಖ್ಯೆ **Th.4489**
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Details of soil sampling sites :

Profiles : P6 and P7

Location : Islampur - P6 and Devapur - P7

Climate : Arid

Parent material : Limestone

Soil order : Vertisols

Sub - order : Usterts

Series : Kagalgomb series - a member of very fine, montmorillonitic, hyperthermic family of Typic Pellusterts.

Competing series : Soils of Tumkur series derived from granite are similar.

Topography : Nearly level (1 - 3 % slope)

Drainage : Moderately well to imperfectly drained

Vegetation : Neem, Aceacia, Tamarind and Banni.

Permeability : Moderate to slow

Land use : Cotton and kharif sorghum are main crops cultivated.

Distribution : Soils are found in parts of Shahapur, Shorapur and Jewargi taluks of Gulbarga district and occupy 16.48% of command area.

Typifying pedon : Kagalgomb clay - cultivated

Horizon	Depth in cm	Description
Ap	0 - 18	Dark gary (10 YR 4/1) dry, very dark gray (10 YR 3/1) moist; Clay; Moderate, medium, subangular blocky; dry hard, moist friable, wet sticky and plastic; strongly calcareous; fine roots; moderate permeability; few calcium nodules; pH 8.9; clear smooth boundary.
A1 ₁	18 - 44	Very dark gray (10 YR 3/1) dry and moist; clay; moderate, medium, angular blocky; moist friable, sticky and plastic; intersecting slickensides; strongly calcareous; fine roots, few calcium nodules; moderately slow permeability; pH 8.9; clear smooth boundary.
A1 ₂	44 - 80	Very dark gray (10 YR 3/1) moist; clay; strong, coarse, angular blocky; moist friable, wet sticky and plastic; intersecting slickensides; strongly calcareous; very few, fine roots, few lime nodules; moderately slow permeability; pH 8.8; diffuse smooth boundary.
A1 ₃	80 - 119	Dark grayish brown (10 YR 4/2) moist; clay; strong, coarse, angular blocky; moist-firm, wet sticky and plastic, intersecting slickensides; strongly calcareous; very few, fine roots; few lime nodules; moderately slow permeability; pH 8.8; clear wavy boundary.
AC1	119 - 139	Dark brown (10 YR 4/3) moist; clay; strong, coarse, angular blocky; moist firm, wet very sticky and plastic; intersecting slickensides prominent; strongly calcareous; many lime nodules; slow permeability; pockets of calcium carbonates; pH 8.9; gradual smooth boundary.
AC2	139 +	Dark brown (10 YR 4/3) moist; clay; strong, coarse, angular blocky; moist-firm, wet very sticky and very plastic, few slickensides and shining faces; few pockets of calcium carbonates; strongly calcareous; pH 8.9; slow permeability.