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WTCER

WATER TECHNOLOGY CENTRE FOR EASTERN REGION
(Indian Council of Agricultural Research)
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PREFACE

For food, fodder, fiber, nutrition and environmental security, sound soil and water management technologies play a vital role. Scientific management of land and water resources, both under irrigated and rainfed farming, requires a thorough understanding of the hydrological properties, water retention characteristics, available water capacities and water transmission characteristics of the soils. This facilitates prevention of waterlogging, salinization and efficient use of available water resources through adoption of preventive measures at proper time in any command area or in a watershed. Preparation of any management strategy in water conservation, irrigation scheduling, drainage and solute migration, and development of various hydrological models require basic information on soil hydro-physical properties. Suitable management practices can be adopted to minimize the risks of poor crop yield and crop failure with the knowledge of water storage capacity of soil in addition to water availability. Agriculture in the State of Chhattisgarh is predominantly rainfed. Although it receives high rainfall and has good ground water resources, most of the farmers grow only one crop in rainy season and most of the fields remain fallow during post rainy season in rainfed areas. In canal irrigated areas, use efficiency of applied water is very low. The State has good scope of irrigation expansion, use of ground water and rainwater conservation. Information on the hydro-physical properties of Chhattisgarh soils is meager. The need of systematic measurement and presentation of these soil properties in relation to efficient water management has been felt since long. This has now been achieved through the research conducted by Water Technology Centre for Eastern Region, Bhubaneswar and is presented in the form of a Research Bulletin. This may help in formulation of improved water management strategies and contingent crop planning for irrigated as well as un-irrigated areas for improving the prospects of yield enhancement and stabilization in this region.

The authors are grateful to the Director General, Deputy Director General (Natural Resource Management) and Assistant Director General (IWM), ICAR, Krishi Bhawan, New Delhi for their valuable support, suggestions and encouragement in carrying out this research work. Our sincere thanks are also due to all the colleagues and staff members of WTCER, Bhubaneswar for their help at times of need. Help rendered by Mr. R.C. Jena (Technical Assistant) in Laboratory Analysis and Er. V.K. Tripathi in layout of the document is duly acknowledged.

We sincerely hope that this bulletin will be of use to the researchers, developmental agencies, line departments, farmers and to all those who are interested in the management of soil and water in this region.

Authors

EXECUTIVE SUMMARY

Information on the physical, chemical and hydrological properties of soil is necessary to formulate improved water management strategies and contingency crop planning for irrigated as well as un-irrigated areas for improving the prospect of yield stabilization. Since information on this aspect is not available for Chhattisgarh soils, an attempt was made to generate information on physical and chemical properties, water retention characteristics, available water capacities and water transmission characteristics of dominant soil sub-groups of Chhattisgarh state.

The state of Chhattisgarh, covering a geographical area of about 14 Mha, lies in the tropical belt of the eastern region of India between 17°43′ to 24°50′ N latitude and 80°15′ to 84°20′ E longitude. The state is bounded by as many as six states: Madhya Pradesh on its north-west, Uttar Pradesh on the north, Bihar on the north-east, Orissa on the east, Andhra Pradesh on the south and Maharashtra on its west. The agro-climate of the state is characterized by transition between hot dry sub-humid to moist sub-humid with dry summers and cool winters. The state receives mean annual rainfall varying between 1200 and 1600 mm. The mean length of growing period (LGP) for the state is 150- 180 days and begins with second half of June with onset of monsoon and exceeds beyond November. According to 'Soil Taxonomy' (7^{th} approximation), soils of Chhattisgarh fall under 5 orders and 9 dominating sub-groups. Entisols covers 19.5% cultivated area of the state, Inceptisols 14.8%, Alfisols 39%, Mollisols 0.3% and Vertisols 26.4%. Dominating 9 sub-groups are Typic Ustorthent (covering an area of 1.6% of the total cultivated area), Lithic Ustorthent (17.9%), Typic Haplustept (9.5%), Vertic Haplustept (5.3%), Typic Rhodustalf (6.1%), Typic Haplustalf (32.9%), Lithic Haplustoll (0.3%), Chromic Haplustert (19.3%) and Typic Haplustert (7.1%). Hydro-physical characteristics of these sub-groups are discussed in this research bulletin for efficient soil and water management.

ENTISOL

Typic Ustorthent and Lithic Ustorthent are the dominating subgroups under this order. Typic Ustorthent was sandy clay loam to clay in texture with clay content ranging from 31.3 to 42.8 per cent. Lithic Ustorthent was sandy clay in texture with clay content ranging from 36.4 to 45.9 per cent. In Typic Ustorthent, bulk density varied from 1.46 to 1.65 Mgm^{-3} and in Lithic Ustorthent it varied from 1.52 to 1.601 Mgm^{-3}. Generally, bulk density and pH increased with soil depth. In 0-15 cm soil layer, $pH_{2.5}$ was 5.60 and 5.62 and in 90-120 cm soil layer it was 6.35 and 6.83 in

Typic Ustorthent and Lithic Ustorthent, respectively. Data on electrical conductivity showed that both the sub-groups were free from salinity problem. In general both sub-groups were low in organic carbon content but in comparison to Lithic Ustorthent, higher organic carbon content was found in Typic Ustorthent. Soils of both the sub-groups were non-calcareous in nature and their $CaCO_3$ content ranged from 0.50 to 2.04 per cent. Higher cation exchange capacity was observed in Typic Ustorthent, where it varied from 13.60 to 17.50 $cmolkg^{-1}$, while in Lithic Ustorthent it varied from 10.90 to 14.90 $cmolkg^{-1}$. Lithic Ustorthent was found deficient in available Zn. Higher saturated hydraulic conductivity was observed in Typic Ustorthent, where it varied from 0.701 to 2.17 cmh^{-1} in comparison to Lithic Ustorthent, where it varied from 0.08 to 1.29 cmh^{-1}. Soil moisture retention at 0.033 MPa varied from 0.220 to 0.278 cm^3cm^{-3} in Lithic Ustorthent, while in Typic Ustorthent it varied from 0.242 to 0.329 cm^3cm^{-3}. Similarly higher water content at 1.5 MPa, available water content and total water capacity were recorded in Typic Ustorthent than in Lithic Ustorthent. High profile water storage capacity was observed in Typic Ustorthent and medium profile water storage capacity was observed in Lithic Ustorthent

INCEPTISOL

Under this order the dominating sub-groups are Typic Haplustept and Vertic Haplustept. Vertic Haplustept have clayey texture with clay content varying from 48.0 to 55.0 per cent. Typic Haplustept is sandy clay loam to clay in texture with clay content ranging from 33.2 to 50.4 per cent. Clay content in the soils generally increased with depth indicating movement of clay from surface to sub-surface layers. Bulk density of the soils varied from 1.32 to 1.65 Mgm^{-3}. Bulk density increased as the depth of the soil increased in all the soil profiles of both sub-groups. Higher organic carbon content was recorded in Vertic Haplustept soil profile, where it varied from 0.179 to 1.132 per cent. In other soil profile of Typic Haplustept it varied from 0.03 to 0.645 per cent. In both the sub-groups and in all the soil profiles of this sub-group, organic carbon content was higher in surface layers than sub-surface layers. All the soils were non-calcareous in nature and their $CaCO_3$ content varied from 0.417 to 1.916 per cent. These soils were slightly acidic to slightly alkaline in reaction. $pH_{2.5}$ of these soils varied from 5.10 to 8.32. In general low pH was observed in surface layers, which increased with the soil depth. $EC_{2.5}$ ranged from 0.01 to 0.10 dSm^{-1} indicating no appreciable accumulation of salts in the soil profile. Higher CEC was observed in Vertic Haplustept than in Typic Haplustept soil profiles. Availability of Zn was low in subsoil layers (below 15–30 cm of surface) of all the profiles except Typic Haplustept of Dantewada. At 0.033 MPa, higher water was retained by Vertic Haplustept than by Typic Haplustept. In surface layers higher saturated hydraulic conductivity, Ks (1.640 cmh^{-1}) was observed in Typic Haplustept than in Vertic Haplustept (0.041 cmh^{-1}). Very high profile water storage capacity was observed in Vertic Haplustept and high profile water storage capacity was observed in Typic Haplustept

ALFISOL

Typic Rhodustalf and Typic Haplustalf are the dominant subgroups under this order. Texture of the soil ranged from sandy clay loam to clay, with clay content varying from 24.0 to 57.5 per cent. Higher clay content was observed in Typic Haplustalf than in Typic Rhodustalf. Clay content in the soils generally increased with depth indicating movement of clay from surface to sub-surface layers. Bulk density also increased with increase in soil depth. Higher bulk density was observed in Typic Rhodustalf, where it varied from 1.55 to 1.61 $Mgm^{-3}$and lower in Typic Haplustalf profile where it varied from 1.36 to 1.452 Mgm^{-3}. Organic carbon (OC) content in the soil generally decreased with depth. Higher organic carbon content was observed in Typic Haplustalf than in Typic Rhodustalf. In general, $pH_{2.5}$ increased with soil depth. In Typic Rhodustalf it varied from 5.31 in 0-15 cm layer to 7.26 in 90-120 cm layer, while in Typic Haplustalf it varied from 4.86 in 0-15 cm soil layer to 5.78 in 90-120 cm soil layer. Data on electrical conductivity showed that both the sub-groups were free from salinity problem. Both the sub-groups were non-calcareous in nature and their $CaCO_3$ content varied from 0.208 to 2.63 per cent. The cation exchange capacity (CEC) varied from 12.9 to 17.20 $cmolkg^{-1}$ in Typic Rhodustalf; and from 10.40 to 15.90 $cmolkg^{-1}$ in Typic Haplustalf. Typic Haplustalf of Dantewada was deficient in Zn availability. Higher saturated hydraulic conductivity (Ks) was observed in Typic Rhodustalf soil profile, where it varied from 1.60 to 2.80 cmh^{-1}. In Typic Haplustalf soil profiles it varied from 0.302 to 1.941 cmh^{-1}. At 0.033 MPa water retention was higher in Typic Haplustalf soil profiles, where it varied from 0.312 to 0.433 cm^3cm^{-3} than in Typic Rhodustalf, where it varied from 0.135 to 0.176 cm^3cm^{-3}. Similar trends were also observed for water retention at 1.5 MPa, available water content and total water capacity of the soils. Profile water capacity per meter depth, calculated from soil-water retention data for Alfisols are presented in Table 14. Very high to high profile water storage capacity was observed in Typic Haplustalf and low profile water storage capacity was observed in Typic Rhodustalf.

MOLLISOL

In this order the dominating sub-group is Lithic Haplustoll. Texture was sandy clay loam to clay with clay content ranging from 27.8 to 41.8 per cent. Bulk density varied from 1.331 to 1.441 Mg m^{-3}. The soil was free from any salt problem and $pH_{2.5}$ varied from 5.83 to 6.28. Organic carbon content was 0.50 per cent in 0-15 cm soil layer and 1.07 per cent in deeper layers. It indicates that due to soil and water erosion organic carbon washed away from surface layers. $CaCO_3$ content ranged from 0.500 to 0.958 per cent, indicating non-calcareous nature of the soil. Cation exchange capacity varied from 13.5 to 21.40 $cmolkg^{-1}$. Exchangeable Ca and Mg ranged from 5.40 to 10.80 and from 4.00 to 7.00 meL^{-1}, respectively. Exchangeable Ca and Mg were higher than Na and K. But in case of water soluble cations, sodium was higher than calcium, magnesium and potassium. The soil profile had uniformly high level of Fe indicating possible occurrence of iron toxicity under flooded field condition. Saturated hydraulic conductivity varied from 0.871 cmh^{-1} in 0-15 cm soil layer to 0.361 cmh^{-1} in 90-120 cm soil layer. Higher water retention at 0.033 and 1.5 MPa, available water content and total water capacity was observed in deeper soil layers. Profile water storage capacity in this sub-group was very high, it was measured at 24.35 cmm^{-1}.

VERTISOL

There are two sub-groups under the order Vertisol, i.e. Chromic Haplustert and Typic Haplustert. Both sub-groups (Chromic Haplustert and Typic Haplustert) were clay in texture with clay content ranging from 45.0 to 50.70 per cent. Higher bulk density was observed in Chromic Haplustert, where it varied from 1.515 to 1.615 Mgm^{-3}. In Typic Haplustert it ranged from 1.373 to 1.542 Mgm^{-3}. In 0-15 cm soil layer, $pH_{2.5}$ values of Chromic Haplustert and Typic Haplustert were 7.2 and 7.3, respectively. In 90-120 cm soil depth, it was 7.78 and 8.08, in the same soil profile. Data on electrical conductivity showed that both the sub-groups were free from any salinity problem. In general both the sub-groups were low in organic carbon content (OC). OC content varied from 0.176 to 0.772 per cent. Higher $CaCO_3$ content was found in Chromic Haplustert, where it varied from 0.833 to 4.374 per cent, while in Typic Haplustert it varied from 0.333 to 0.958 per cent. Cation exchange capacity varied from 19.10 to 24.20 $cmolkg^{-1}$ in Chromic Haplustert and 19.20 to 23.50 $cmolkg^{-1}$ in Typic Haplustert. Mn and Zn availability were generally higher in Chromic Haplustert than in Typic Haplustert profiles. Very low saturated hydraulic conductivity (0.035 to 0.102 cmh^{-1}) was observed in Chromic Haplustert. In Typic Haplustert it varied from 0.141 to 0.322 cmh^{-1}. At 0.033 MPa, water retention varied from 0.359 to 0.401 cm^3cm^{-3} in Chromic Haplustert and 0.387 to 0.467 cm^3cm^{-3} in Typic Haplustert. At 1.5 MPa, it varied from 0.172 to 0.184 cm^3cm^{-3} in Chromic Haplustert and from 0.184 to 0.237 cm^3cm^{-3} in Typic Haplustert. Slightly higher available water content was observed in Typic Haplustert (0.189 to 0.230 cm^3cm^{-3}) than in Chromic Haplustert (0.168 to 0.193 cm^3cm^{-3}). Very high profile water storage capacity was observed in Typic Haplustert and high profile water storage capacity was observed in Chromic Haplustert.

Erodibility of Major Soil Groups

Erosion indices, viz. clay ratio, dispersion ratio and erosion index of 9 soils were determined. Highest clay ratio was found in Typic Rhodustalf and followed by Lithic Haplustoll, Typic Ustorthent, Typic Haplustept and the lowest in Vertic Haplustept. Highest dispersion ratio was found in Typic Haplustept and Typic Rhodustalf and the lowest was in Typic Haplustalf. Mean erosion index was highest in Typic Haplustept (42.10) and the lowest in Lithic Ustorthent.

Soil, water and crop management implications

Based on rainfall pattern, temperature, soil type and existing cropping pattern, Chhattisgarh state can be divided into three natural regions/ zones i.e. North hill region/zone; Plain region/zone and Bastar plateau region/zone. Soils of North hill region belong to Entisol, Inceptisol and Mollisol orders and the dominating sub-groups are Typic Ustorthent; Typic Haplustept; Typic Haplustalf and Lithic Haplustoll. Adoption of suitable soil and water conservation measures will be necessary to improve water-use efficiency in all the soils of this region. Use of organic materials like green manure, FYM, and FYM + green manure both will prove very effective for improving water-use efficiency and crop production in these soils. Profile water storage capacity of these soils indicated that Lithic Haplustoll and Typic Haplustalf have very high and Typic Ustorthent and Typic Haplustept have high water storage capacity. The ψ-θ relationship, hydraulic conductivity, soil-water diffusivity and profile water storage capacity of these soils suggested that application of medium to heavy irrigation at long intervals, may be practiced in Lithic Haplustoll and Typic Haplustalf for higher water-use efficiency without any adverse effect. Frequent irrigations using small amount of water each time will be required to improve use efficiency of water applied to Typic Ustorthent and Typic

Haplustept sub-groups. In Lithic Haplustoll and Typic Haplustalf, cultivation of a second crop without irrigation is possible after rainy season provided it is sown immediately after harvest of *kharif* crop and in *kharif* season short-duration high-yielding rice variety is grown. In Typic Ustorthent and Typic Haplustept, a second crop without irrigation is possible either as *paira* crop or with mulching, otherwise at least one irrigation is required.

The soils of plain region belong to Inceptisol, Alfisol and Vertisol orders and dominating sub-groups are Typic Haplustept, Vertic Haplustept, Typic Rhodustalf, Chromic Haplustept and Typic Haplustert. *In-situ* conservation of water will be necessary to improve water-use efficiency in Vertic Haplustept, Chromic Haplustert and Typic Rhodustalf. Data on soil moisture retention characteristics, hydraulic conductivity, soil-water diffusivity and profile water storage capacity suggest that frequent irrigation using small amount of water each time will be required to improve use efficiency of water applied to Typic Rhodustalf. Drip or sprinkler irrigation, mulching, *in-situ* conservation of water and application of organic material and proper bunding will prove useful to improve use efficiency of applied water and increase crop yield in this sub-group. Application of medium to heavy irrigation at long intervals may be practiced in Typic Haplustept, Vertic Haplustept, Chromic Haplustert and Typic Haplustert for higher water-use efficiency without any adverse effect. In Vertic Haplustept and Typic Haplustert, cultivation of a second crop without irrigation is possible after rainy season provided it is sown immediately after the harvest of *kharif* crop. In Typic Haplustept and Chromic Haplustert sub-group, a second crop without irrigation is possible either as a *paira* crop or with mulch. In Typic Rhodustalf, second crop is not possible without irrigation. All the soil groups need application of improved water management practices for achieving higher water-use efficiency and crop yields.

Soils of Bastar plateau region belong to Entisol, Inceptisol and Alfisol orders and dominating sub-groups are Lithic Ustorthent, Typic Haplustept and Typic Haplustalf. Application of organic materials like FYM or compost to all the sub-groups and particularly Lithic Ustorthent will improve the water retention and storage capacity of soil. Data on soil-water retention and available water content suggest that light and frequent irrigation and use of mulch will be useful to improve use efficiency of applied water in these sub-groups. The frequency of irrigation in these soils may be reduced through use of mulches. Use of drip or sprinkler irrigation will be effective for increasing water-use efficiency. Adoption of suitable water management practices for *in situ* conservation of water will be necessary for these sub-groups. Application of suitable soil and water conservation measures are necessary particularly for Typic Haplustept sub-group. In Typic Haplustalf and Typic Haplustept, cultivation of a second crop without irrigation will be possible after rainy season provided it is sown immediately after the harvest of *kharif* crop or as a *paira* crop or with mulch. In Lithic Ustorthent, second crop is not possible without irrigation.

Under Hill region, priority should be given to soil and water conservation for maintaining soil health and preserving the resource base. Technologies for *in-situ* moisture conservation hold a key for enhanced water-use efficiency in various crops. In plain region, emphasis should be laid on developing technologies for enhancing input efficiency through water-nutrient, water-tillage and identifying water-use efficient cropping sequences and intercropping systems. In plateau region of Bastar, technologies for upland diversification hold promise. In entire Chhattisgarh state, use of green manuring and organic manures should be encouraged. Entisol (Lithic Ustorthent), Inceptisol and Alfisols (Typic Haplustalf) were found to be deficient in available Zn. Application of Zn fertilizer will be required to realize crop yield potentials in these soils.

Prediction of water storage capacity of the soil

For prediction of available soil-water, sand, silt and cation exchange capacity accounted for 44.4 per cent variation; sand, silt, clay, bulk density, organic carbon and calcium carbonate contributed to only 49.9 per cent; and sand and silt alone accounted for 38.0 per cent variation. Sand, silt, clay, bulk density, organic carbon and $CaCO_3$ accounted for 75.7 per cent variation in water retention at field capacity; sand, silt and cation exchange capacity together accounted for 82.7 per cent variation, and sand and silt alone accounted for 68.8 per cent. Hence, available water cannot be predicted as accurately as water content at field capacity and wilting point. It was better to estimate available water using the predicted values of field capacity and wilting point.

1. INTRODUCTION

Preparation of sound strategies for water management, irrigation scheduling, drainage and solute migration, soil and water conservation, development of various hydrological models, water budging, and scheduling of any agricultural operation require basic informations on soil hydraulic properties. Efficient use of limited water resources for optimization of crop and water productivity and proper land and water management, both under irrigated and rainfed farming, require a thorough understanding of pertinent hydrological properties, the soil-water retention characteristics, available water capacities and water transmission characteristics of soils. Suitable management practices can be adopted to minimize the risks of poor crop yields and crop failure with the knowledge of water storage capacity of soil in addition to water availability.

Chhattisgarh state is predominantly is an agrarian one and famous for cultivation of rice and called "rice-bowl" of the country. About 80 per cent population depends on agriculture for its livelihood. Agriculture in the State is predominantly rainfed and the rainfall varies from 750 mm in northern part to about 1600 mm in the Dandakaranya (Bastar) area of the state. The irrigation facilities are lagging behind in the state. Out of 14 Mha of available land, about 44 per cent is used for cultivation. About 18 percent of the cultivated land is being irrigated. In irrigated areas, use-efficiency of applied irrigation water is very low (30 per cent or less). The state has got good scope of irrigation expansion and rainwater conservation. Information on the hydro-physical properties of soil may help in formulating improved water management strategies and contingency crop planning for irrigated as well as un-irrigated areas for improving the prospect of yield stabilization in this region. Since information on this aspect is not available for Chhattisgarh soils, an attempt was made to generate information on soil-water retention characteristics, available water capacities and water transmission characteristics of dominant soil sub-groups of Chhattisgarh state.

Susceptibility of soil to severe erosion hazards and partial waterlogging in early stages of crop growth followed by seasonal drought during the rest of the period has been identified as a potential threat to sustainability of the livelihood system of the people in this region. Adequate base-line information on erodibility of different soil types of Chhattisgarh was not available for devising appropriate erosion control measures. Hence erosion indices and water storage capacity were determined for surface as well as sub-surface layers of the soil profiles, and they were related to various physico-chemical properties of the soils.

2. AGRO-CLIMATIC CONDITIONS OF CHHATTISGARH

The state of Chhattisgarh, covering a geographical area of about 14 Mha, lies in the tropical belt of the eastern region of India between 17°43′ to 24°50′ N latitude and 80°15′ to 84°20′ E longitude. The state is bounded by as many as six states, Madhya Pradesh on its north-west, Uttar Pradesh on the north, Bihar on the north-east, Orissa on the east, Andhra Pradesh on the south and Maharashtra on its west. The important rivers of the state are Mahanadi, Shivanand and Indravati. Mahanadi is the most important river of the state forming a Mahanadi valley, between the Vindhyas in the south. The agro-climate of the state is characterized by transition between hot dry sub-humid to moist sub-humid with dry summers and cool winters. The mean annual temperature varies from 25 to 28°C. The mean summer (April- May- June) temperature varies between 30 to 32 °C and may rise to a maximum of 34 to 42°C in May. The mean winter (December- January- February) temperature varies from 17 to 19 °C and may drop to a minimum of 8 to 13°C in January. The state receives mean annual rainfall varying between 1200 and 1600 mm, which covers more than 85 percent of annual demand of PET ranging between 1400 and 1600 mm. The south-western monsoon sets in the first week of June and extends till the first half of October. The peak period of rainy season comprising end of June to September covers about 95 per cent of the total monsoon rainfall. The mean length of growing period (LGP) for the state is 150- 180 days and begins with second half of June with onset of monsoon and exceeds beyond November.

On the basis of rainfall pattern, temperature, soil type and existing cropping pattern the Chhattisgarh state broadly divided into three major agro-climatic zones. These are i.) Chhattisgarh plain zone, ii.) Bastar plateau zone and iii.) North hill zone of Chhattisgarh. Chhattisgarh plain zone receives rainfall between 1300 and 1600 mm. The rainfall is extremely erratic and major part of the precipitation occurs during July to August. The weather is warm and humid. The net irrigated area in the region is only 21.6 per cent of the net cultivated area. Canal system forms the major source of irrigation. The major crop of the region is rice. Bastar plateau zone receives an annual rainfall between 1200 to 1600 mm with the maximum precipitation during July and August. About 62.8 percent area of this zone comes under forest. Net sown area is about 8.3 lakh ha (21.4%) and only 13, 273 ha is under irrigation. The major crop of the region is rice but the productivity is very low, less than 1 t/ha. North hill zone of Chhattisgarh is situated between 20°-12′ and 24°-6′ N latitude and 80°-1′ to 84°-8′ E longitude. The altitude ranges from 293 m to 1200 m above m.s.l. The climate of the zone is sub-humid which is mild in summer and moderate in winter. The mean annual rainfall is about 455 mm and about 87 per cent of annual rainfall is received during June to September. Total geographic area of the zone is about 72.6 lakh ha, which is 12.6 per cent of the state's area out of which about 45.2 per cent is under forests. The gross cultivated area is 28.2 lakh ha, which is 37.1 percent of the geographical area of the zone and only 4 per cent gross cropped area is under irrigation.

2.1 Land utilization pattern in Chhattisgarh

Table 1: Land Utilisation (area in '000 ha) in Chhatisgarh

Items	1999-2000
Total geographical area according to village papers	13603
Area under forest	6099
Area not available for cultivation	1029
Other un-cultivated land excluding fallow land	
(a) Permanent pastures and other grazing land	866
(b) Cultivable waste land	331
Sub Total	1197
Fallow land	
(a) Fallow land other then current fallows	221
(b) Current fallows	229
Sub Total	450
Total uncultivated land including fallow land (Sub Total)	1647
Net area sown	4828
Area sown more than once	960
Gross cropped area	5788

Source: Chhatisgarh in Charts & Graphs 2001, Directorate of Economics & Statistics, Govt. of Chhatisgarh.

The district-wise land-use classification is presented in Table 2

Table 2 : District-wise Land Use Classification (area in ha) in Chhattisgarh

District	Total Geo-graphical Area	Geographical Area				Not Available Land for Agriculture		Land Put to Non-Agricul-tural Units	Fallow Land	
		Forest			Total Geo-graphical Area According to Village Papers	Revenue Forest	Barren and Un-Cultivable Land		Cur-rent Fallow	Fallow Land Other than Current Fallow
		Re-curred Forest	Pro-tected Forest	Others						
Raipur	1344628	175617	180535	50216	938260	120091	9664	88964	14520	10537
Mahasamund	496236	-76143	34056	0	386037	30269	6694	36499	2769	1621
Dhamtari	408193	205632	6922	0	195639	8686	1558	28461	1462	1171
Durg	870180	44613	30298	0	795269	24697	10714	87648	10667	8489
Rajnandgaon	802252	94317	66502	0	641433	98544	18931	46764	10240	3715
Kauiardha	434705	71058	92774	0	270873	25488	9947	6436	2104	348
Bastar	1701604	322417	38835	497551	842801	277990	39672	36294	30286	16194
Kanker	643371	158566	27825	0	456980	94229	19305	31088	13141	6824
Dantewada	1560877	496881	36843	0	1027153	460617	45129	41106	53331	36116
Bilaspur	856885	111094	107244	0	638547	113865	10110	40942	6080	3880
Korba	446674	30939	48500	0	367235	9677.	2351	35011	3751	3083
Janjgeer (Champa)	714544	0	283114	0	431430	189976	30695	29254	4522	3791
Surguja	1603440	238141	330749	0	1034550	202604	7886	78322	0	0
Koriya	597770	200061	152813	0	244896	48107	12852	21274	0	0
Raigarh	652774	149699	0	0	503075	58315	14290	46259	6644	1375
Jashpur	645741	114726	0	0	531015	62316	103472	26673	6607	0
Chhattisgarh	13779874	2489904	1437010	547767	9305193	1825471	343270	680995	166124	97144

Source : Land Record Dept., Govt. of Chhattisgarh.

Table 3. District-wise area (ha) under different soil sub-groups in Chhattisgarh

Districts	Typic Ustor thent	Lithic Ustor thent	Typic Haplus tept	Vertic Haplus tept	Typic Haplus tept	Typic Rhodus talf	Lithic Haplus toll	Typic Haplus tert	Chromic Haplus tert	Total
Raipur	—	114543	142759	7206	—	—	—	—	—	161508
Mahasamund	—	—	8601	11418	—	—	—	—	—	20019
Dhamtari	—	—	42744	—	5634	84013	—	—	—	132391
Durg	—	106244	14879	—	109988	—	—	1055	10244	242410
Rajnandgaon	5770	9042	23552	178859	436960	—	—	221504	337528	1213215
Kabardha	—	2000	5400	—	44469	—	—	5500	4559	61928
Bilaspur	—	—	—	—	—	—	—	39373	86353	125726
Janjgeer	—	—	—	—	—	—	—	—	49728	49728
Korba	—	—	—	—	5820	—	—	—	—	5820
Raigarh	—	53590	84528	—	35377	76880	8000	—	—	258375
Jashpur	—	37351	1000	—	18846	10000	1137	—	—	68334
Surguja	54135	11290	3567	—	150807	33348	—	—	—	253147
Koriya	—	—	—	—	5900	22120	—	—	—	28020
Bastar	—	20465	—	5720	—	—	—	—	239355	265540
Kanker	—	270825	—	—	318782	—	—	—	—	589607
Dantewada	—	46762	27103	—	—	119328	—	—	—	193193

2.2. Soils of Chhattisgarh

Soils of Chhattisgarh are mainly developed by the actions and interactions of relief, parent material and climate. Biotic features, mainly the natural vegetation follows the climatic patterns. According to 'Soil Taxonomy' (7^{th} approximation), soils of Chhattisgarh fall under 5 orders and 9 dominating sub-groups. Entisols covers 19.5% cultivated area of the state, Inceptisols 14.8%, Alfisols 39%, Mollisols 0.3% and Vertisols 26.4%. Dominating 9 sub-groups are Typic Ustorthent (covering an area of 1.6% of the total cultivated area), Lithic Ustorthent (17.9%), Typic Haplustept (9.5%), Vertic Haplustept (5.3%), Typic Rhodustalf (6.1%), Typic Haplustalf (32.9%), Lithic Haplustoll (0.3%), Chromic Haplustert (19.3%), Typic Haplustert (7.1%). Hydro-physical characteristics of these sub-groups are discussed in this research bulletin for efficient soil and water management. District-wise aerial distribution of soils in nine sub-groups is presented in Table 3.

3. METHODOLOGY

3.1 Method of sampling soil profiles

Profile soil samples were collected from thirteen sites spread throughout Chhattisgarh state, representing 9 dominant sub-groups. The sampling sites are described in Table 1 and shown in Fig.1. Three soil profiles were dug for each site and samples were collected from 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm depth of each profile.

3.2 Determination of physico-chemical properties of soils

Processed soil samples (< 2 mm size) were analyzed for mechanical composition following international pipette method. Bulk density was estimated on undisturbed samples collected with metal cores of 4.2 cm diameter and 5.8 cm height (Klute 1986). Organic carbon content, calcium carbonate and cation exchange capacity and exchangeable cations of the soils were determined following standard procedures (Jackson 1976). Soluble cations were determined in the extract of 1:2.5 soil:water suspension.

3.3 Determination of micronutrient availability in soils

Availability of Fe, Mn, Zn and Cu in the soils (at 6 different depths) of 13 sites was determined by extracting the processed soil samples with DTPA (Lindsay and Norvell, 1978) and measuring concentrations of the cations in DTPA- extract with atomic absorption spectrometer "Varian Spectra 220"

3.4 Determination of water retention characteristics of soils

For determination of water retention, undisturbed soil samples were collected using metal cores of 5-cm diameter from all these depths. Water retained by soil at different tensions was estimated by using pressure plate apparatus (Richards 1965). Water retention at -10 kPa soil-water potential was considered as field capacity value for light textured soils and that at -33 kPa tension for medium and heavy textured soils. Water retained between field capacity and wilting point was considered as available water. Profile water storage capacity of 5, 5-10, 10-15, 15-20 and 20 cm m^{-1} depth were categorized as very low, low, medium, high and very high, respectively (Rao and Prasadini 1998). Regression analysis has been carried-out to develop equations for predicting water retention at field capacity, wilting point and available water.

3.5 Determination of diffusivity and hydraulic conductivity of soils

From the experimental Ks values and complete water retention characteristics curve, unsaturated hydraulic conductivity and diffusivity functions were developed using RETC-computer code that uses van-Genuchten–Mualem equation (Mualem 1976, van Genuchten 1980, van Genuchten and Nielsen 1985) to transform water retention data to unsaturated hydraulic conductivity and soil-water diffusivity functions.

Table 4. List of soil sampling sites

Soil order	Soil sub-group	Profile Site No.	District	Geo-positions of soil sampling site	
				N latitude	E longitude
Entisol	Typic Ustorthent	1	Surguja	22° 13′	84° 30′
	Lithic Ustorthent	2	Bastar	20° 04′	82° 43′
Inceptisol	Typic Haplustept	3	Bilaspur	22° 11′	83° 24′
	Typic Haplustept	4	Koriya	23° 35′	83° 26′
	Typic Haplustept	5	Surguja	23° 51′	84° 38′
	Vertic Haplustept	6	Raipur	21° 16′	82° 57′
	Typic Haplustept	7	Dantewada	19° 01′	82° 36′
Alfisol	Typic Rhodustalf	8	Korba	22° 39′	83° 52′
	Typic Haplustalf	9	Surguja	23° 11′	84° 10′
	Typic Haplustalf	10	Dantewada	18° 23′	82° 05′
Mollisol	Lithic Haplustoll	11	Jashpur	22° 51′	84° 59′
Vertisol	Chromic Haplustert	12	Janjgir	21° 53′	84° 59′
	Typic Haplustert	13	Bilaspur	21° 55′	83° 12′

3.6 Determination of Soil erodibility

Soil erodibility can be evaluated by the measurement of soil loss in run-off plots, which is quite expensive, time consuming and has been feasible only for a few soil types. Several empirical equations have been suggested in the past to assess soil erodibility. These equations are also very cumbersome as they require determination of many parameters together. Erosion index (EI) is a simple and reliable pa-

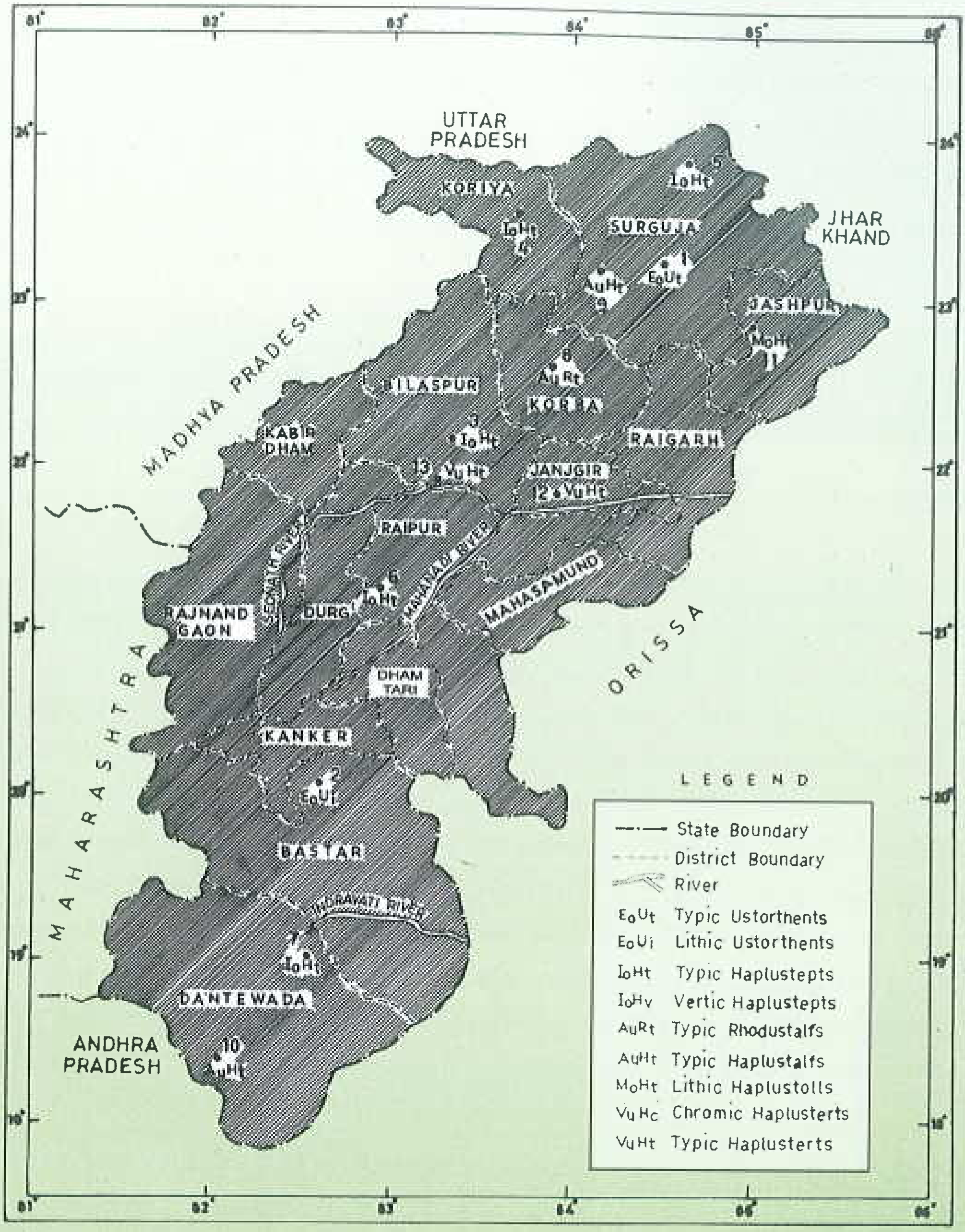

Fig. 1: Map of Chhattisgarh showing soil profile sampling sites described in Table1

rameter (Sahi et al. 1977; Gupta et al. 1998; Singh et al. 2005) for determining soil erodibility. It provides a numerical expression of the potential for a soil to erode. Higher the index value, the greater will be the investment needed to maintain the sustainability of the soil.

Erosion index

Erosion index was computed from the following relationship described by Sahi et al. (1977):

Erosion index = Dispersion ratio/(clay/0.5 water holding capacity)

Dispersion ratio was calculated from the following relationship described by Middleton (1930):

$$Dispersion\ ratio = \frac{Water\ dispersible\left(silt + clay\right)}{Total\left(silt + clay\right)} \times 100$$

Water dispersible silt + clay was determined by dispersing 25 g soil in 1000 ml distilled water without adding any dispersing agent, shaking end-over-end for 20 times and pipetting out 20 ml of soil suspension from 10 cm depth.

4. RESEARCH FINDINGS

4.1 Soil Order: ENTISOL

These soils are recently formed soils with little or no evidence of development of pedogenic horizons. They have ochric epipedon and some times anthropic epipedon. These soils are formed on steep, actively eroding slopes, on flood plains receiving new deposits of alluvium. They are formed on a variety of climatic conditions. The parent material is also variable which may be recent alluvium, sand dunes or even a variety of rocks. Large areas of Entisols in alluvial bottom lands are cultivated for a variety of grain and vegetable crops and used for pastures. In Chhattisgarh, the dominating sub-order is Orthents and dominating sub-groups are Typic Ustorthent and Lithic Ustorthent.

4.1.1 Physico-chemical and hydrological characteristics

Physico-chemical and hydrological properties of Entisols are presented in Table 5 and 6. Typic Ustorthent was sandy clay loam to clay in texture with clay content ranging from 31.3 to 42.8 per cent. Lithic Ustorthent was sandy clay in texture with clay content ranging from 36.4 to 45.9 per cent. In Typic Ustorthent, bulk density varied from 1.460 to 1.649 Mgm^{-3} and in Lithic Ustorthent, it varied from 1.52 to 1.601 Mgm^{-3}. Generally, bulk density and pH increased with soil depth. In 0-15 cm soil layer, $pH_{2.5}$ was 5.60 and 5.62 and in 90-120 cm soil layer, it was 6.35 and 6.83 in Typic Ustorthent and Lithic Ustorthent, respectively. Data on electrical conductivity showed that both the sub-groups were free from salinity problem. In general, both sub-groups were low in organic carbon content but in comparison to Lithic Ustorthent, higher organic carbon content was found in Typic Ustorthent. Soils of both the sub-groups were non-calcareous in nature and their $CaCO_3$ content ranged from 0.50 to 2.04 per cent.

Data on water soluble and exchangeable cations and cation exchange capacity are given in Table 5b and 6b. Higher cation exchange capacity was observed in Typic Ustorthent, where it varied from 13.60 to 17.50 cmol kg^{-1}, while in Lithic Ustorthent it varied from 10.90 to 14.90 cmol kg^{-1}. Similarly higher exchangeable cations were found in Typic Ustorthent than in Lithic Ustorthent. Water soluble cations were low in both the soils.

Data on DTPA extractable Fe, Mn, Zn and Cu in Typic Ustorthent are presented in Table 5d and Lithic Ustorthent are given in Table 6d. Considering the most acceptable critical limits of the micronutrients (Fe: 4.5 mg/kg, Mn: 2.0 mg/kg, Zn: 0.6 mg/kg and Cu: 0.2 mg/kg), both the soils had high to very high levels of Fe, Mn and Cu. Typic Ustorthent profile had higher micronutrient availability than that in Lithic Ustorthent. Lithic Ustorthent soil was deficient in Zn while Typic Ustorthent had sufficient level of available Zn.

Data on saturated hydraulic conductivity (Ks), moisture content at saturation, at 0.033 MPa, 1.5 MPa, available water content and total water capacity are presented in Table 5c and 6c. Higher saturated hydraulic conductivity was observed in Typic Ustorthent, where it varied from 0.701 to 2.17 cmh^{-1} in comparison to Lithic Ustorthent, where it varied from 0.08 to 1.29 cmh^{-1}. Soil-water retention characteristics (ψ-θ relationships) of the soils are presented in Fig 2a and 3a. At 0.033 MPa it varied between 0.220 and 0.278 cm^3cm^{-3} in Lithic Ustorthent, while in Typic Ustorthent it varied between 0.242 and 0.329 cm^3cm^{-3}. Similarly higher water content at 1.5 MPa, available water content and total water capacity were recorded in Typic Ustorthent than in Lithic Ustorthent. Profile water capacity per meter depth, calculated from soil-water retention data for Entisols are presented in Table 7. High profile water storage capacity was observed in Typic Ustorthent and medium profile water storage capacity was observed in Lithic Ustorthent.

Data on soil-water diffusivity and hydraulic conductivity in the soil as a function of water content are presented in Fig 2b, 2c and 3b, 3c. Both the parameters varied

Table 5a: Physico-chemical characteristics of Typic Ustorthent at Surguja

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.01	5.60	0.658	2.041	46.6	18.1	35.3	sc	1.46
15 -30	0.02	6.36	0.315	0.917	52.1	16.6	31.3	scl	1.48
30 - 45	0.01	6.48	0.343	1.458	52.1	16.6	31.3	scl	1.52
45 - 60	0.01	6.48	0.257	1.791	51.1	16.1	32.8	scl	1.55
60 - 90	0.01	6.47	0.286	0.958	42.6	17.1	40.3	c	1.62
90 -120	0.01	6.35	0.217	0.917	42.6	14.6	42.8	c	1.65

Table. 5b. Water soluble and exchangeable cations and cation exchange capacity of Typic Ustorthent at Surguja

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	
0 - 15	1.2	0.0	3.7	Trace	5.0	3.00	1.04	0.08	14.30
15 -30	0.4	2.8	4.0	Trace	6.0	2.80	1.10	0.08	13.60
30 - 45	0.6	1.0	4.0	Trace	6.4	4.00	1.12	0.08	16.30
45 - 60	1.2	1.8	4.0	Trace	7.6	2.40	1.16	0.08	16.10
60 - 90	0.8	1.2	3.7	Trace	7.6	3.20	1.12	0.16	17.40
90 -120	1.0	1.2	3.7	Trace	6.2	4.60	1.10	0.20	17.50

Table. 5c. Hydraulic characteristics of Typic Ustorthent at Surguja

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	1.427	0.416	0.311	0.110	0.201	3.015
15 -30	2.171	0.376	0.242	0.084	0.158	2.370
30 - 45	2.110	0.380	0.253	0.084	0.169	2.535
45 - 60	0.847	0.386	0.262	0.089	0.173	2.595
60 - 90	0.752	0.444	0.329	0.123	0.206	9.870
90 -120	0.701	0.457	0.326	0.143	0.183	9.780

Table 5d. Micronutrient availability in Typic Ustorthent at Surguja

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	299.8	49.2	1.62	2.64
15 -30	89.2	44.0	1.02	1.78
30 - 45	69.6	41.6	0.78	1.88
45 - 60	78.0	20.0	0.54	1.86
60 - 90	55.8	50.2	0.62	1.30
90 -120	47.8	35.0	0.56	0.92

Table 6a: Physico-chemical characteristics of Lithic Ustorthent at Bastar

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.01	5.62	0.313	2.000	55.1	8.5	36.4	sc	1.52
15 -30	0.01	5.56	0.402	0.667	48.1	9.0	42.9	sc	1.55
30 - 45	0.01	6.36	0.015	0.917	51.6	6.0	42.4	sc	1.57
45 - 60	0.01	6.65	0.104	0.458	50.6	6.0	43.4	sc	1.58
60 - 90	0.01	6.96	0.030	1.375	47.1	7.0	45.9	sc	1.59
90 -120	0.01	6.83	0.060	0.500	51.1	7.0	41.9	sc	1.60

Table 6b: Water soluble and exchangeable cations and cation exchange capacity of Lithic Ustorthent at Bastar

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	0.8	1.6	4.0	Trace	4.40	4.60	0.90	0.16	10.90
15 -30	0.2	3.0	4.8	Trace	8.00	2.40	0.96	0.16	11.50
30 - 45	1.6	1.2	4.8	Trace	6.60	6.20	0.96	0.16	14.90
45 - 60	1.2	1.2	4.0	Trace	5.60	7.20	0.96	0.16	14.30
60 - 90	2.0	1.2	4.9	Trace	6.00	6.40	1.00	0.16	14.80
90 -120	1.8	1.0	4.8	Trace	8.40	3.00	1.00	0.08	13.90

Table 6c: Hydraulic characteristics of Lithic Ustorthent at Bastar

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	1.291	0.328	0.220	0.104	0.116	1.740
15 -30	1.011	0.415	0.225	0.137	0.088	1.320
30 - 45	0.821	0.435	0.242	0.142	0.100	1.500
45 - 60	0.731	0.448	0.256	0.151	0.105	1.575
60 - 90	0.184	0.516	0.278	0.161	0.117	8.340
90 -120	0.084	0.351	0.222	0.121	0.101	6.660

Table 6d. Micronutrient availability in Lithic Ustorthent at Bastar

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	17.7	13.4	0.22	1.20
15 -30	18.9	6.5	0.26	1.10
30 - 45	15.3	4.6	0.82	1.46
45 - 60	13.0	2.2	0.50	0.90
60 - 90	13.4	2.4	0.38	1.68
90 -120	11.8	2.4	0.44	0.88

Table 7: Water storage capacity of the Entisol profiles

Profile No.	Name of the sub-group	Profile water Storage capacity (cmm^{-1} depth)	Category for profile water capacity
1	Lithic Ustorthent	18.53	High
2	Typic Ustorthent	10.66	Medium

with soil type and depth. In general, values of soil-water diffusivity and conductivity decreased with decrease in water content in both soils but magnitude of change was different. Magnitude was higher in Lithic Ustorthent than in Typic Ustorthent. Similarly higher magnitude was observed in surface than in sub-surface layers.

4.2 Soil Order: INCEPTISOL

These soils represent the early stage of soil formation, which is more advanced than that of Entisol but still short of the degree of development found in Alfisol. The Inceptisols are developed recently owing to the alteration of the parent material but without much leaching and accumulation of material in the sub-soil. Profile development is too weak in these soils. Normally these soils are formed in low, rolling parts of the landscape in and around steep mountain fronts. In sequences of alluvial terraces these soils are formed at intermediate positions between Entisols nearest the stream and other developed soils farther away from the stream. In Chhattisgarh, the dominating sub-groups under this orderare Typic Haplustept and Vertic Haplustept.

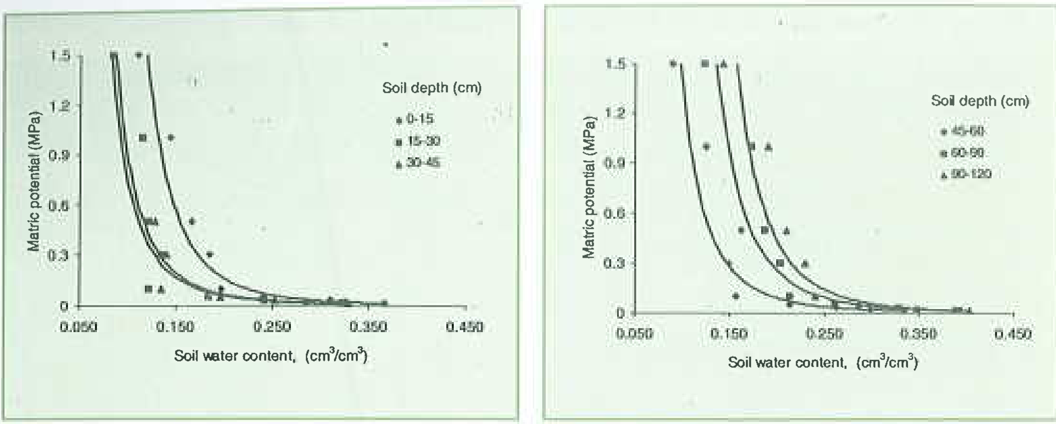

Fig.2a. Matric potential as a function of soil water content in Typic Ustorthent at Surguja

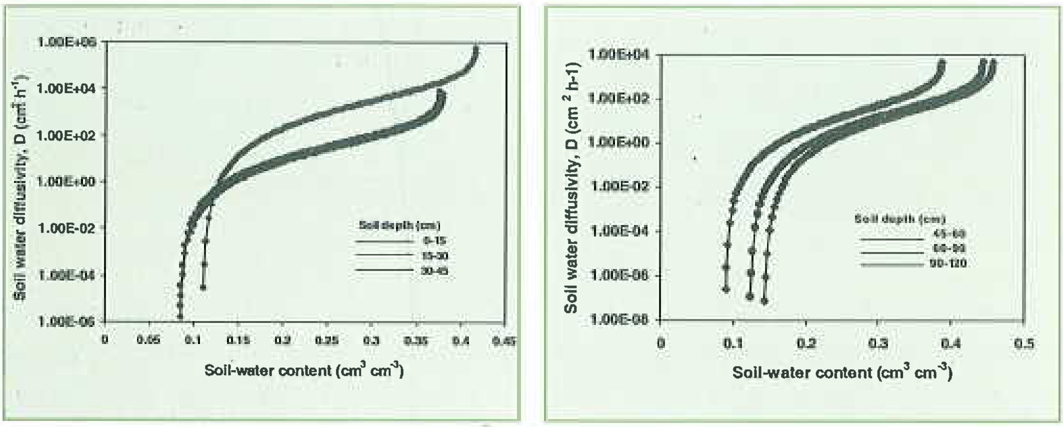

Fig. 2b. Soil water diffusivity as a function of water content in Typic Ustorthent at Surguja

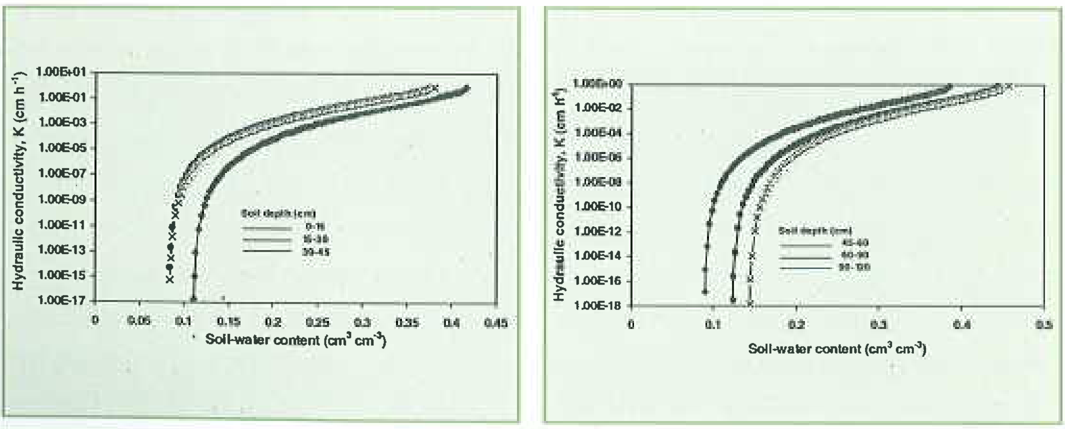

Fig.2c. Hydraulic conductivity as a function of water content in Typic Ustorthent at Surguja

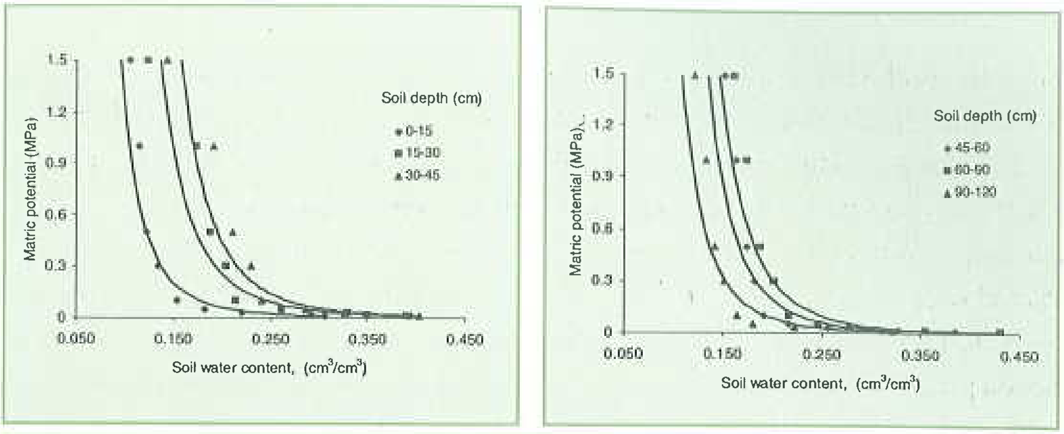

Fig.3a. Matric potential as a function of soil water content in Lithic Ustorthent at Bastar

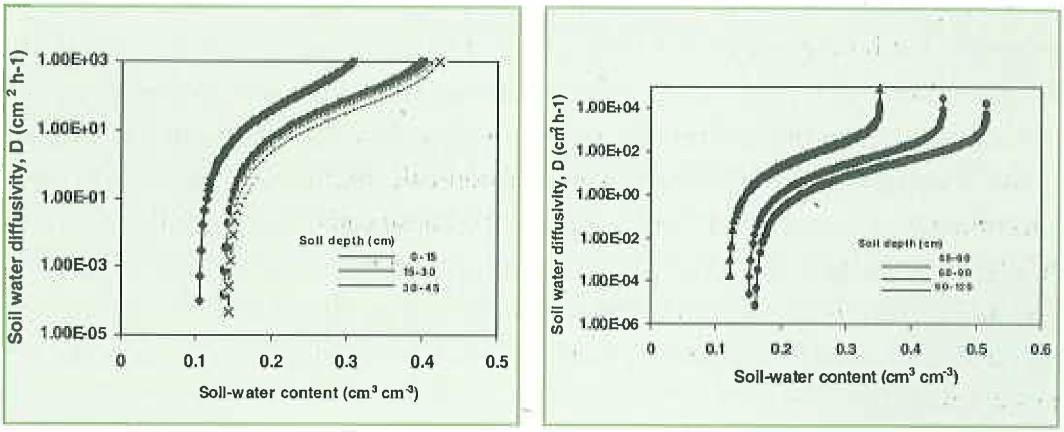

Fig. 3 b. Soil water diffusivity as a function of water content in Lithic Ustorthent at Bastar

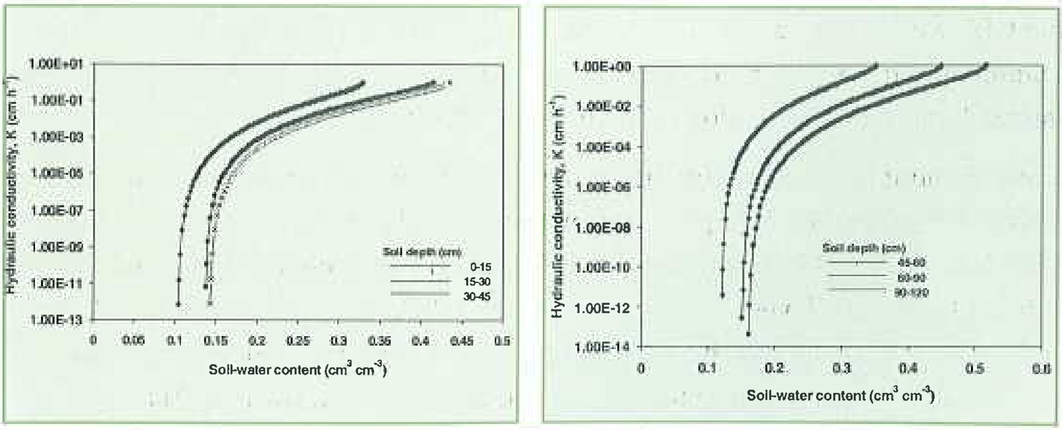

Fig. 3 c. Hydraulic conductivity as a function of water content in Lithic Ustorthentat Bastar

4.2.1 Physico-chemical and hydrological characteristics

Physico-chemical and hydrological characteristics of Inceptisols are presented in Table 8 to 12. Vertic Haplustept have clayey texture with clay content varying from 48.0 to 55.0 per cent. The remaining soil profiles of 3, 4, 5 and 7 of sub-group Typic Haplustept are sandy clay loam to clay with clay content ranging from 33.2 to 50.4 per cent. Clay content in the soils generally increased with depth indicating movement of clay from surface to sub-surface layers. Bulk density of the soils varied from 1.32 to 1.65 Mgm^{-3}. Bulk density increased as the depth of the soil increased in all the soil profiles of both sub-groups. Higher organic carbon content was recorded in Vertic Haplustept soil profile, where it varied from 0.179 to 1.132 per cent. In other soil profile of Typic Haplustept, it varied from 0.03 to 0.645 per cent. Among all the soil profiles of Typic Haplustept, lowest organic carbon content was found in profile No.5, where it varied from 0.03 to 0.283 per cent and highest in profile No. 3, where it varied from 0.272 to 0.645 per cent. In both the sub-groups and in all the soil profiles of this sub-group, organic carbon content was higher in surface layers than sub-surface layers. All the soils were non-calcareous in nature and their $CaCO_3$ content varied from 0.417 to 1.916 per cent. These soils were slightly acidic to slightly alkaline in reaction. $pH_{2.5}$ of these soils varied from 5.10 to 8.32. In general low pH was observed in surface layers, which increased with the soil depth. $EC_{2.5}$ ranged from 0.01 to 0.10 dSm^{-1} indicating no appreciable accumulation of salts in the soil profile.

Water soluble and exchangeable cations and cation exchange capacity of Inceptisol are presented in Table 8b to 12b. The CEC varied from 10.00 to 26.00 cmol kg^{-1}. Higher CEC was observed in Vertic Haplustept than in Typic Haplustept soil profiles. Similar trend was observed for exchangeable cations. Low to very low amount of water soluble cations were found in all the soil profiles.

Data on micronutrient availability in soil layers of Typic Haplustept profiles are presented in Table 8d (for Bilaspur), 9d (for Koriya), 10d (for Surguja), and 12d (for Dantiwada), and in soil layers of Vertic Haplustept are presented in Table 11d. All the soils had sufficient levels of available Fe, Mn and Cu in 0-120 cm dep profiles. Availability of Zn was low in the subsoil layers (soil below 15-30 cm from the surface) of all the profiles except that in Typic Haplustept of Dantiwada. DTPA- extractable Mn in Vertic Haplustept was lower than that in Typic Haplustept profile.

Saturated hydraulic conductivity (Ks), moisture content at saturation, 0.033 MPa, 1.5 MPa, available water content and total water capacity are presented in Table 8c to 12c and soil-water retention characteristics (ψ-θ relationships) are presented in Fig 4a and 8a. At 0.033 MPa, highest water was retained by Vertic Haplustept (profile No. 6) followed by Typic Haplustept (profile No. 5). Water retention was lowest in case of Typic Haplustept (0.231 to 0.317 $cm3cm^{-3}$). At 1.5 MPa, highest amount of water was retained by profile No. 6 (Vertic Haplustept) and lowest by profile No. 4 (Typic Haplustept). In surface layers, the highest saturated hydraulic conductivity, Ks (1.640 cmh^{-1}) was observed in profile No. 4 of Typic Haplustept followed by profile No. 5 of the same sub-group. The lowest saturated hydraulic conductivity (0.041 cmh^{-1}) was observed in Vertic Haplustept. Profile water capacity per meter depth, calculated from soil-water retention data for Inceptisols are presented in Table 13. Very high profile water storage capacity was observed in Vertic Haplustept and high profile water storage capacity was observed in Typic Haplustept

Data on soil-water diffusivity, D(θ) and hydraulic conductivity, K(θ)the soils as a function of water content are presented in Fig. 4b to 8b and 4c to 8c, respectively. Both the parameters varied with soil texture. Values of soil-water diffusivity and conductivity were lower in Vertic Haplustept than in Typic Haplustept. In all the soil profile, unsaturated hydraulic conductivity, K(θ) and soil-water diffusivity, D(θ), decreased with decrease in their water content. Magnitude of the change in K(θ) and D (θ) with water content, , varied with soil texture. Higher magnitude was observed in Typic Haplustept than in Vertic Haplustept soil profiles.

Table. 8a. Physico-chemical characteristics of Typic Haplustept at Bilaspur

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.07	6.55	0.645	0.917	48.7	18.1	33.2	scl	1.32
15 -30	0.04	6.90	0.501	0.833	49.2	15.1	35.7	sc	1.41
30 - 45	0.02	7.08	0.272	0.375	44.2	22.6	33.2	cl	1.46
45 - 60	0.01	7.46	0.286	1.000	43.2	18.6	38.2	cl	1.55
60 - 90	0.02	7.43	0.343	0.875	37.7	21.6	40.7	c	1.58
90 -120	0.01	7.45	0.343	0.583	38.2	20.1	41.7	c	1.58

Table.8b. Water soluble and exchangeable cations and cation exchange capacity of Typic Haplustept at Bilaspur

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	1.4	2.2	3.1	Trace	6.80	2.80	1.04	0.08	13.90
15 -30	1.4	2.4	2.6	Trace	7.60	4.20	1.04	0.08	16.80
30 - 45	0.8	2.2	3.5	Trace	6.00	3.60	1.00	0.08	12.60
45 - 60	1.6	1.2	3.5	Trace	7.00	3.20	1.04	0.08	14.40
60 - 90	2.2	1.0	2.6	Trace	8.40	3.20	1.10	0.16	16.20
90 -120	2.0	1.2	3.5	Trace	6.20	7.60	1.14	0.16	18.30

Table. 8c. Hydraulic characteristics of Typic Haplustept at Bilaspur

Soil depth (cm)	Ks (cm h^{-1})	θs ($cm^3 cm^{-3}$)	θ($cm^3 cm^{-3}$)at 0.033 MPa	θ($cm^3 cm^{-3}$) at 1.5 MPa	Available water content ($cm^3 cm^{-3}$)	Total water capacity (cm)
0 - 15	1.110	0.498	0.307	0.114	0.193	2.895
15 -30	1.041	0.526	0.336	0.125	0.211	3.165
30 - 45	1.121	0.520	0.309	0.119	0.190	2.850
45 - 60	0.621	0.534	0.354	0.149	0.205	3.075
60 - 90	0.322	0.580	0.370	0.173	0.197	11.100
90 -120	0.281	0.598	0.373	0.174	0.199	11.190

Table 8d. Micronutrient availability inTypic Haplustept at Bilaspur

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	229.4	26.0	2.20	4.24
15 -30	123.6	23.6	1.52	3.74
30 - 45	31.4	28.0	0.36	2.04
45 - 60	27.2	20.0	0.30	2.24
60 - 90	36.5	15.2	0.50	2.86
90 -120	39.4	9.8	1.12	2.42

Table. 9a. Physico-chemical characteristics of Typic Haplustept at Koriya

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.08	5.22	0.429	0.708	48.0	15.0	37.0	sc	1.45
15 -30	0.02	5.69	0.172	0.875	45.5	11.5	43.0	sc	1.45
30 - 45	0.01	6.05	0.143	0.542	43.0	12.5	44.5	c	1.46
45 - 60	0.01	6.11	0.143	1.333	41.0	12.0	47.0	c	1.50
60 - 90	0.01	6.20	0.100	1.916	38.5	14.5	47.0	c	1.50
90 -120	0.01	6.14	0.086	1.333	40.0	16.5	43.5	c	1.52

Table. 9b. Water soluble and exchangeable cations and cation exchange capacity of Typic Haplustept at Koriya

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	
0 - 15	1.0	0.4	4.0	Trace	5.80	1.40	1.00	0.08	10.00
15 -30	1.4	0.6	4.9	Trace	6.20	2.40	1.04	0.08	11.70
30 - 45	1.2	0.0	5.0	Trace	5.00	3.60	0.96	0.08	11.80
45 - 60	1.6	0.2	4.9	Trace	6.00	3.40	1.00	0.08	12.70
60 - 90	0.8	1.2	4.8	Trace	6.00	3.20	1.00	0.08	13.70
90 -120	2.0	0.0	4.8	Trace	6.80	2.80	1.10	0.08	12.10

Table. 9c. Hydraulic characteristics of Typic Haplustept at Koriya

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	1.640	0.321	0.231	0.075	0.156	2.340
15 -30	1.011	0.339	0.243	0.093	0.150	2.250
30 - 45	0.811	0.362	0.288	0.113	0.175	2.625
45 - 60	0.302	0.372	0.294	0.116	0.178	2.670
60 - 90	0.301	0.394	0.317	0.120	0.197	9.510
90 -120	0.502	0.351	0.275	0.107	0.168	8.250

Table 9d. Micronutrient availability in Typic Haplustept at Koriya

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	43.8	64.4	1.56	1.00
15 -30	13.3	46.8	0.48	0.64
30 - 45	11.5	23.0	0.32	0.42
45 - 60	8.7	12.0	0.38	0.42
60 - 90	7.4	8.1	0.26	0.40
90 -120	8.5	11.8	0.44	0.50

Table. 10a. Physico-chemical characteristics of Typic Haplustept at Surguja

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.03	5.62	0.283	0.917	44.0	17.5	38.5	cl	1.46
15 -30	0.03	7.37	0.104	0.750	41.0	16.0	43.0	c	1.47
30 - 45	0.05	6.60	0.030	0.500	37.5	15.5	47.0	c	1.48
45 - 60	0.05	6.25	0.030	0.833	36.0	18.0	46.0	c	1.48
60 - 90	0.04	6.20	0.030	1.500	40.5	15.0	44.5	c	1.50
90 -120	0.04	6.40	0.030	1.250	38.0	16.5	45.5	c	1.56

Table. 10b. Water soluble and exchangeable cations and cation exchange capacity of Typic Haplustept at Surguja

Soil depth (cm)	Water soluble cations (me L^{-1})				Particle size analysis (%)				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	0.2	2.2	4.0	Trace	11.40	0.80	0.07	0.16	14.90
15 -30	1.8	0.8	4.9	Trace	6.00	10.00	0.90	0.16	17.60
30 - 45	3.0	1.0	4.9	Trace	6.40	15.60	0.70	0.16	25.50
45 - 60	1.2	1.8	4.9	Trace	7.80	14.80	0.64	0.16	26.00
60 - 90	1.8	2.2	4.9	Trace	7.80	13.60	0.64	0.16	23.50
90 -120	2.2	1.2	4.9	Trace	7.60	11.60	0.70	0.16	21.50

Table. 10c. Hydraulic characteristics of Typic Haplustept at Surguja

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	1.411	0.508	0.331	0.176	0.155	2.325
15 -30	0.853	0.525	0.366	0.208	0.158	2.370
30 - 45	0.412	0.628	0.453	0.267	0.186	2.790
45 - 60	0.302	0.621	0.446	0.259	0.187	2.805
60 - 90	0.422	0.531	0.423	0.253	0.170	12.690
90 -120	0.491	0.553	0.434	0.255	0.179	13.020

Table 10d. Micronutrient availability in Typic Haplustept at Surguja

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	175.8	87.0	1.14	3.10
15 -30	14.0	14.5	0.44	0.98
30 - 45	11.6	8.7	0.30	0.66
45 - 60	15.6	9.4	0.44	0.74
60 - 90	13.2	6.3	0.40	0.86
90 -120	12.6	7.0	0.34	0.92

Table. 11a. Physico-chemical characteristics of Vertic Haplustept at Raipur

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.08	6.55	1.132	0.375	30.5	21.5	48.0	c	1.32
15 -30	0.07	7.80	0.298	0.542	30.5	16.0	53.5	c	1.45
30 - 45	0.06	7.92	0.238	0.500	30.0	15.5	54.5	c	1.50
45 - 60	0.06	7.91	0.179	0.292	28.5	17.5	54.0	c	1.55
60 - 90	0.06	8.32	0.238	0.667	29.5	15.5	55.0	c	1.60
90 -120	0.07	7.70	0.224	0.542	29.0	17.0	54.0	c	1.65

Table. 11b. Water soluble and exchangeable cations and cation exchange capacity of Vertic Haplustept at Raipur

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	5.6	0.4	4.9	Trace	10.40	6.00	0.80	0.48	19.60
15 -30	4.2	0.6	4.9	Trace	14.00	4.80	1.12	0.44	23.30
30 - 45	5.2	0.6	4.9	Trace	12.40	8.40	1.10	0.40	24.60
45 - 60	5.2	0.6	4.9	Trace	12.00	9.20	1.04	0.28	23.80
60 - 90	4.8	2.2	4.9	Trace	12.80	8.20	1.04	0.36	24.70
90 -120	5.0	1.8	5.0	Trace	12.80	8.40	1.04	0.28	23.70

Table. 11c. Hydraulic characteristics of Vertic Haplustept at Raipur

Soil depth (cm)	Ks (cm h^{-1})	θs ($cm^3\,cm^{-3}$)	θ($cm^3\,cm^{-3}$) at 0.033 MPa	θ($cm^3\,cm^{-3}$) at 1.5 MPa	Available water content ($cm^3\,cm^{-3}$)	Total water capacity (cm)
0 - 15	0.140	0.572	0.449	0.237	0.212	3.180
15 -30	0.101	0.589	0.475	0.241	0.234	3.510
30 - 45	0.081	0.630	0.511	0.285	0.226	3.390
45 - 60	0.075	0.613	0.490	0.251	0.239	3.585
60 - 90	0.050	0.642	0.528	0.303	0.225	15.840
90 -120	0.041	0.608	0.502	0.264	0.238	15.060

Table 11d. Micronutrient availability in Vertic Haplustept at Raipur

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	104.4	64.4	1.28	4.08
15 -30	10.7	11.3	0.48	1.52
30 - 45	11.5	9.1	0.44	1.20
45 - 60	11.0	8.0	0.38	1.10
60 - 90	9.4	5.8	0.26	0.98
90 -120	10.6	6.6	0.38	1.22

Table. 12a. Physico-chemical characteristics of Typic Haplustept at Dantewada

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.10	5.18	0.596	0.500	25.1	35.5	39.4	cl	1.32
15 -30	0.06	5.10	0.328	0.708	27.1	33.5	39.4	cl	1.39
30 - 45	0.03	5.30	0.253	0.625	27.6	28.5	43.9	c	1.40
45 - 60	0.03	5.50	0.387	1.083	25.1	24.0	50.9	c	1.42
60 - 90	0.02	5.80	0.268	1.208	31.1	19.5	49.4	c	1.43
90 -120	0.01	6.10	0.030	0.417	34.6	19.5	45.9	c	1.45

Table. 12b. Water soluble and exchangeable cations and cation exchange capacity of Typic Haplustept at Dantewada

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	0.6	1.4	4.0	Trace	8.40	3.20	0.96	0.16	11.90
15 -30	2.0	0.0	4.0	Trace	6.40	4.40	0.96	0.16	12.80
30 - 45	1.8	0.0	4.0	Trace	9.20	2.40	0.96	0.16	14.10
45 - 60	1.8	0.0	4.0	Trace	8.40	4.40	1.00	0.16	14.20
60 - 90	1.0	0.6	4.0	Trace	10.80	2.80	0.96	0.16	15.30
90 -120	2.0	0.0	4.8	Trace	10.40	2.40	0.96	0.16	14.20

Table. 12c. Hydraulic characteristics of Typic Haplustept at Dantewada

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	0.177	0.551	0.344	0.140	0.204	3.060
15 -30	0.164	0.561	0.359	0.146	0.213	3.195
30 - 45	0.166	0.568	0.360	0.166	0.194	2.910
45 - 60	0.156	0.588	0.407	0.221	0.186	2.790
60 - 90	0.152	0.580	0.378	0.213	0.165	11.340
90 -120	0.142	0.576	0.364	0.209	0.155	10.920

Table 12d. Micronutrient availability in Typic Haplustept at Dantewada

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	104.6	120.0	0.80	3.76
15 -30	89.8	122.2	0.68	7.34
30 - 45	40.4	81.4	0.52	3.16
45 - 60	23.4	31.8	0.74	2.00
60 - 90	21.0	36.2	0.58	2.06
90 -120	22.4	51.2	0.36	1.18

Table:13. Water storage capacity of the Inceptisol profiles

Profile No	Name of the sub-group	Profile water Storage capacity (cm m^{-1} depth)	Category for profile water capacity
3	Typic Haplustept	19.89	High
4	Typic Haplustept	17.48	High
5	Typic Haplustept	17.18	High
6	Vertic Haplustept	22.80	Very high
7	Typic Haplustept	18.46	High

4.3 Soil Order: ALFISOL

Alfisols are base-rich mineral soils characterized by a light-coloured surface horizon over a clay enriched argillic sub-surface horizon. These soils are rich in Fe, Al oxides with base saturation of more than 35 per cent. Alfisols are more strongly weathered than the Inceptisols, but less so than the Ultisols. Thin to thick clay coatings (cutans) are observed on the bed faces in their B-horizons. These soils tend to develop under varied types of climate and vegetation. Removal of flocculating agents, like Ca-Mg carbonates and bicarbonates, is a prerequisite for the movement of clay under the influence of percolating water. In Chhattisgarh, the dominating sub-groups under Alfisol are Typic Rhodustalf and Typic Haplustalf.

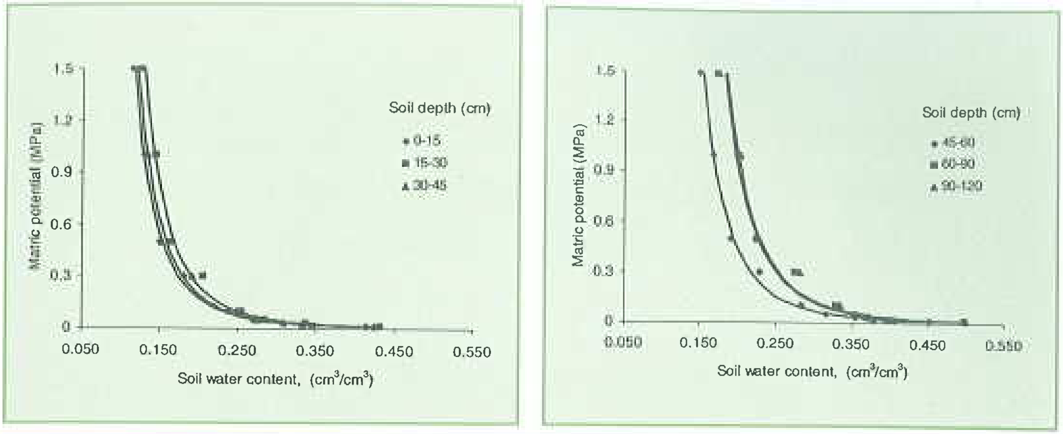

Fig.4a. Matric potential as a function of soil water content in Typic Haplustept at Bilaspur

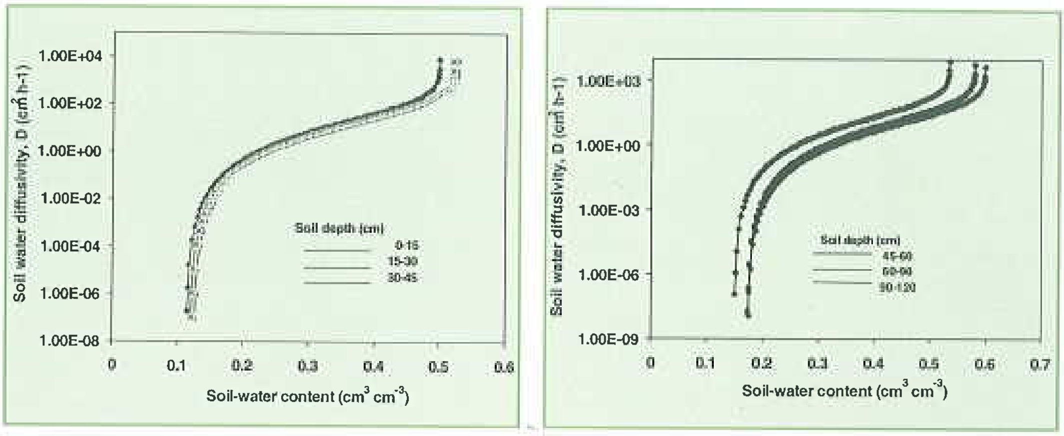

Fig. 4 b. Soil water diffusivity as a function of water content in Typic Haplustept at Bilaspur

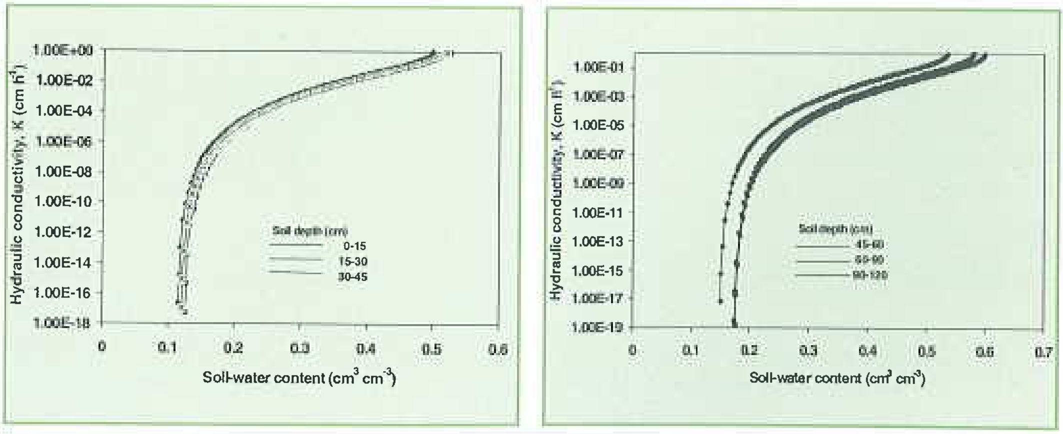

Fig. 4c. Hydraulic conductivity as a function of water content in Typic Haplustept at Bilaspur

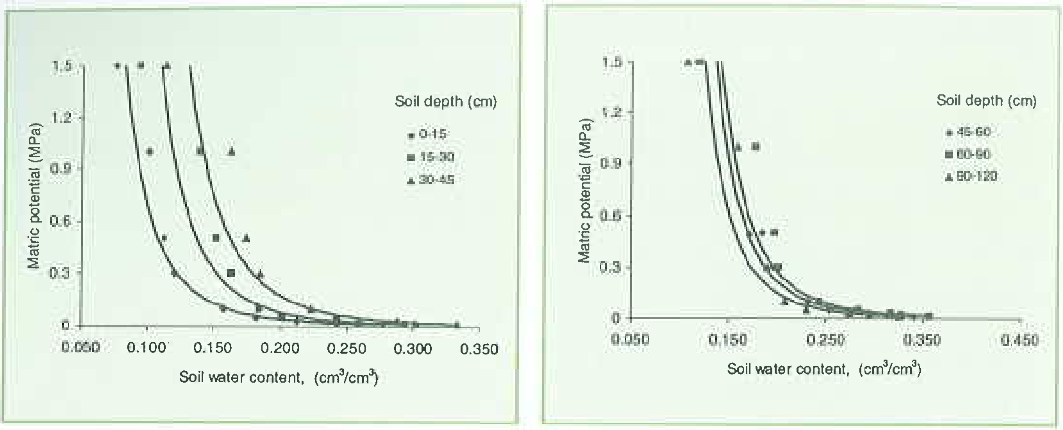

Fig. 5a. Matric potential as a function of soil water content in Typic Haplustept at Koriya

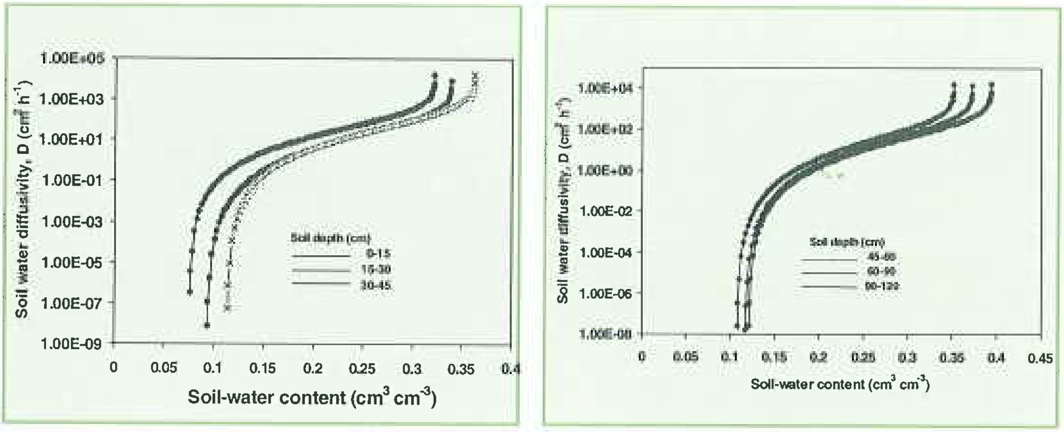

Fig. 5 b. Soil water diffusivity as a function of water content in Typic Haplustept at Koriya

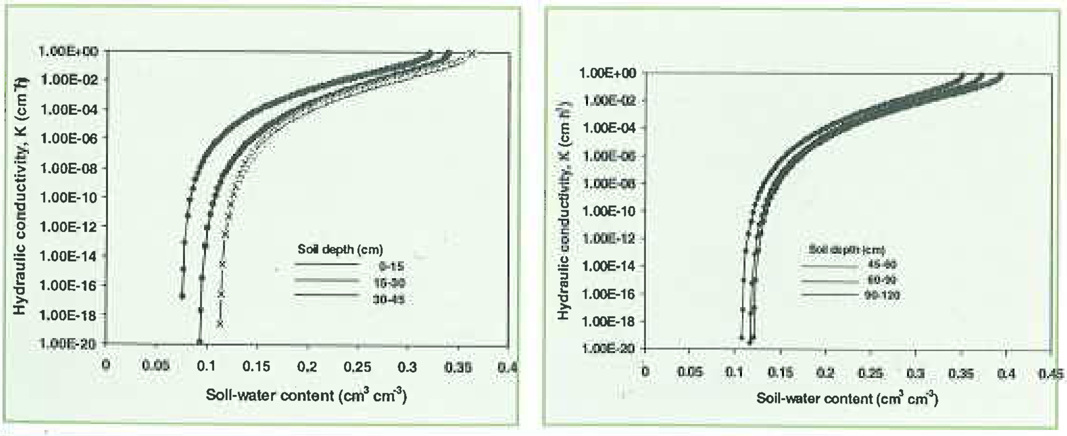

Fig.5 c. Hydraulic conductivity as a function of water content in Typic Haplustept at Koriya

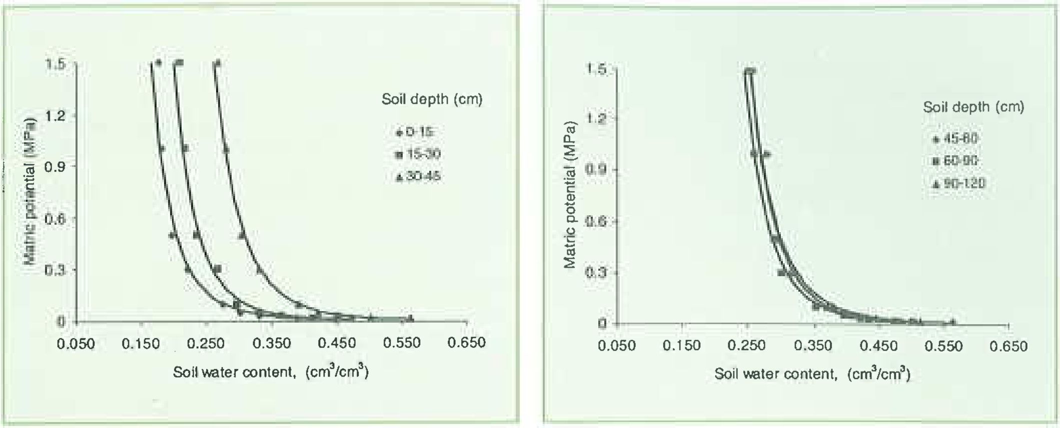

Fig. 6a. Matric potential as a function of soil water content in Typic Haplstept at Surguja

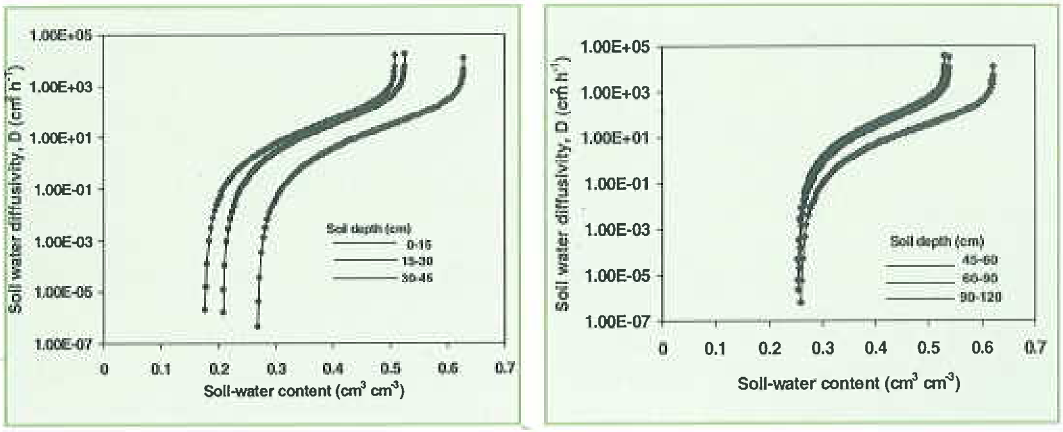

Fig. 6 b. Soil water diffusivity as a function of water content in Typic Haplustept at Surguja

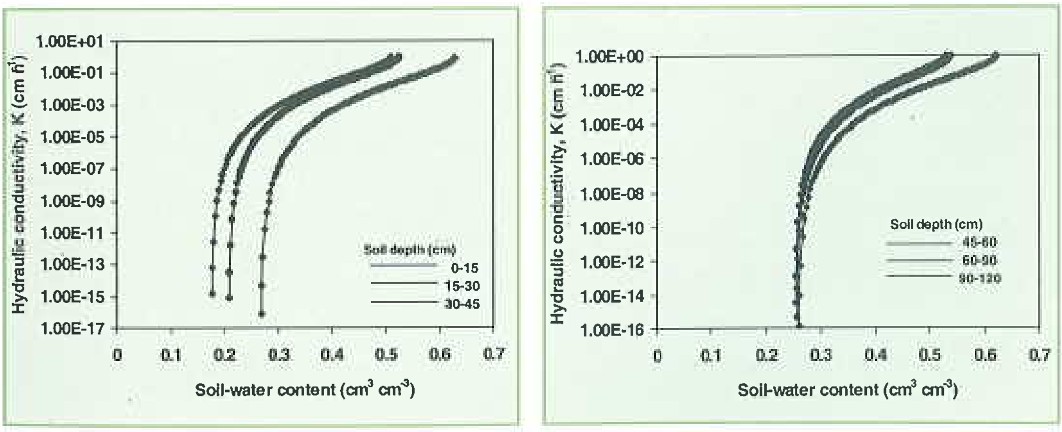

Fig. 6. c. Hydraulic conductivity as a function of water content in Typic Haplustept at Surguja

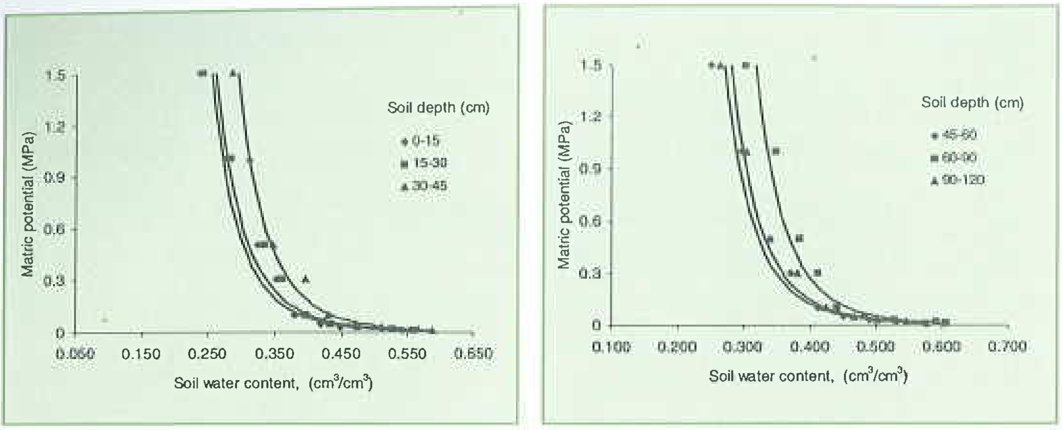

Fig. 7a. Matric potential as a function of soil water content in Vertic Haplustept at Raipur

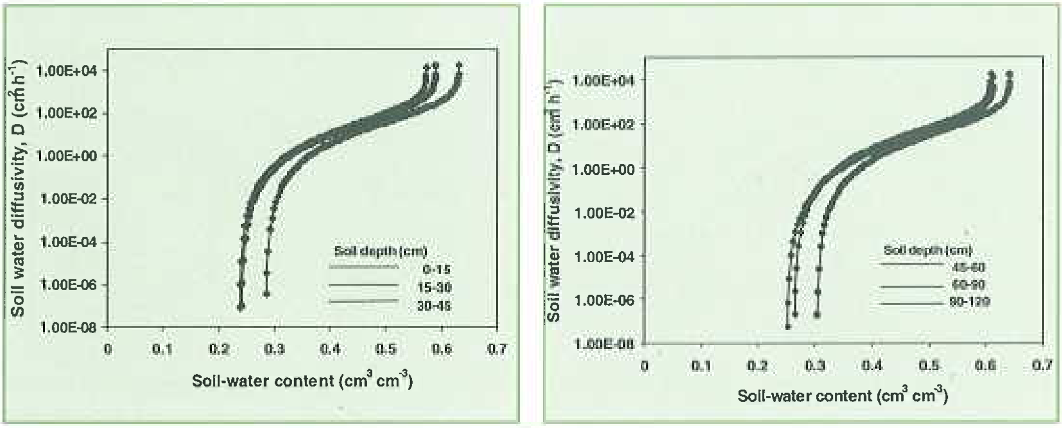

Fig. 7 b. Soil water diffusivity as a function of water content in Vertic Haplustept at Raipur

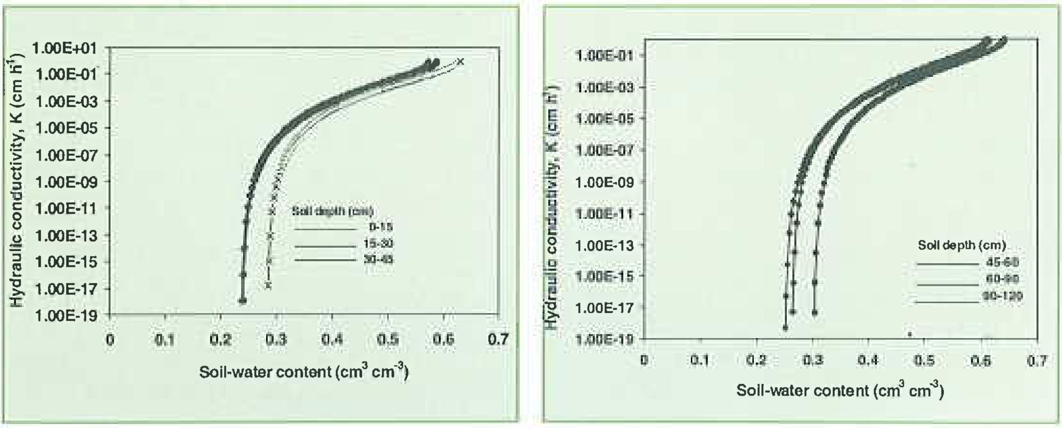

Fig. 7 c. Hydraulic conductivity as a function of water content in Vertic Haplustept at Raipur

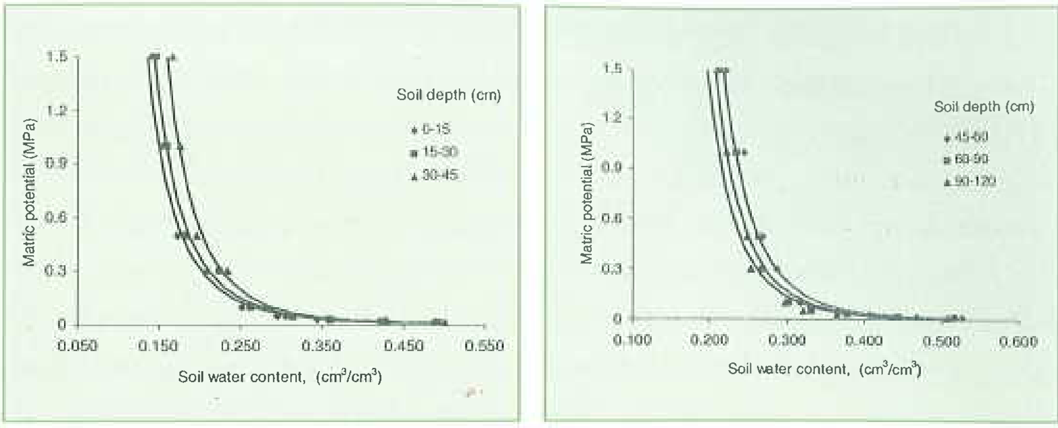

Fig. 8a. Matric potential as a function of soil water content in Typic Haplustept at Dantewada

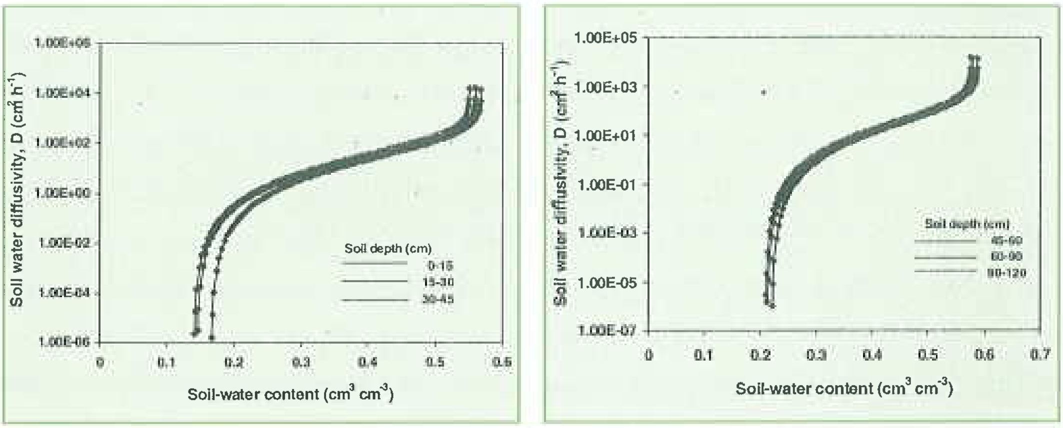

Fig. 8 b. Soil water diffusivity as a function of water content in Typic Haplustept at Dantewada

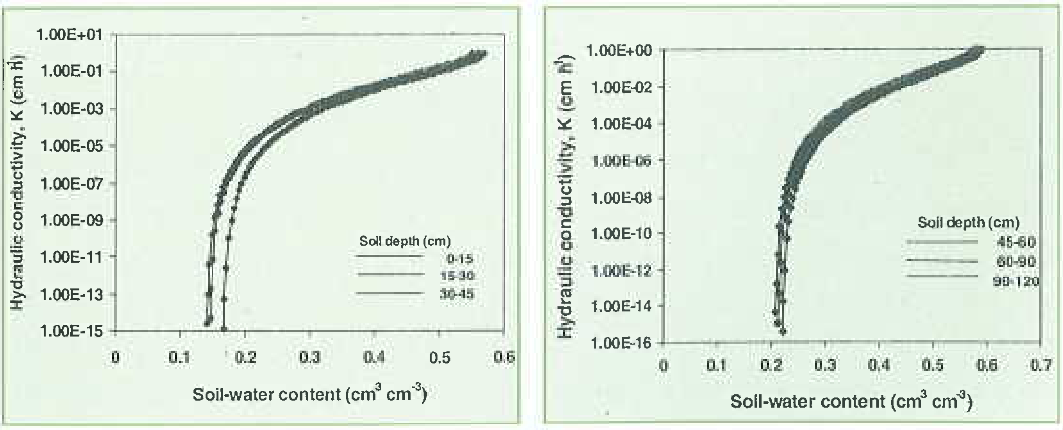

Fig. 8 c. Hydraulic conductivity as a function of water content in Typic Haplustept at Dantewada

4.3.1 Physico-chemical and hydrological characteristics

Physico-chemical and hydrological characteristics of the Alfisol profiles are presented in Table 14 to 17. Texture of the soil ranged from sandy clay loam to clay, with clay content varying from 24.0 to 57.5 per cent. Higher clay content was observed in Typic Haplustalf profile No. 10 followed by profile No. 9 and lowest clay content was observed in profile No. 8 Typic Rhodustalf. Clay content in the soils generally increased with depth indicating movement of clay from surface to sub-surface layers. Bulk density also increased with increase in soil depth. Higher bulk density was observed in Typic Rhodustalf, where it varied from 1.55 to 1.61 $Mgm^{-3}$and lower in Typic Haplustalf profile No. 10, where it varied from 1.36 to 1.452 Mgm^{-3}. Organic carbon (OC) content in the soil generally decreased with depth. Higher organic carbon content was observed in Typic Haplustalf than in Typic Rhodustalf. In Typic Haplustalf, profile No. 10, it varied from 0.18 to 0.48 per cent, while in Typic Rhodustalf, profile No. 8, it varied from 0.143 to 0.286 per cent. In general, $pH_{2.5}$ increased with soil depth. In Typic Rhodustalf it varied from 5.31 in 0-15 cm layer to 7.26 in 90-120 cm layer, while in Typic Haplustalf it varied from 4.86 in 0-15 cm soil layer to 5.78 in 90-120 cm soil layer. Data on electrical conductivity showed that both the sub-groups were free from salinity problem. Both the sub-groups were non-calcareous in nature and their $CaCO_3$ content varied from 0.208 to 2.63 per cent. The cation exchange capacity (CEC) varied from 12.9 to 17.20 cmol kg^{-1} in Typic Rhodustalf; and from 10.40 to 15.90 cmol kg^{-1} in Typic Haplustalf. Higher amount of exchangeable calcium and magnesium in comparison to sodium and potassium was observed in both soil sub-groups. Very low quantity of water soluble cations was present in both soils sub-groups.

Data on DTPA-extractable Fe, Mn, Zn and Cu in the soil layers of Alfisols profiles are presented in Table 14d (for Typic Rhodustalf), Table 15d (for Typic Haplustalf of Surguja) and 16d ((for Typic Haplustalf of Dantewada). Typic Rhodustalf had lower Fe and higher Mn content than that in Typic Haplustalf profile. Zn deficiency was indicated in Typic Haplustalf of Dantiwada but not in Typic Haplustalf of Surguja and Typic Rhodustalf of Korba. DTPA-extractable Cu in Typic Haplustalf were higher than that in Typic Rhodustalf profile.

Saturated hydraulic conductivity (Ks), water content at saturation, 0.033 MPa, 1.5 MPa, available water content and total water capacity are presented in Table 14c to 16c. Highest saturated hydraulic conductivity (Ks) was observed in Typic Rhodustalf soil profile, where it varied from 1.60 to 2.80 cmh^{-1}. In Typic Haplustalf soil profiles it varied between 0.302 to 1.941 cmh^{-1}. Soil-water retention characteristics (ψ-θ relationship) of the soils are presented in Fig 9a to 11a. At 0.033MPa water retention was higher in Typic Haplustalf soil profiles, where it varied from 0.312 to 0.433 cm^3cm^{-3} than in Typic Rhodustalf, where it varied from 0.135 to 0.176 cm^3cm^{-3}. Similar trends were also observed for water retention at 1.5 MPa, available water content and total water capacity of the soils. Profile water capacity per meter depth, calculated from soil-water retention data for Alfisols are presented in Table 17. Very high to high profile water storage capacity was observed in Typic Haplustalf and low profile water storage capacity was observed in Typic Rhodustalf

Data on soil-water diffusivity, D (θ) and hydraulic conductivity, K(θ) in the soils as a function of water content are presented in Fig. 9b to 11b and 9c to 11c, respectively. Both the parameters varied with soil texture. Values of soil-water diffusivity and conductivity were lower in Typic Rhodustalf than in Typic Haplustalf. In all the soil profiles, unsaturated hydraulic conductivity, K(θ) and soil-water diffusivity, D(θ), decreased with decrease in water content. Magnitude of the change in K(θ) and D (θ) with water content, , varied with soil texture. Higher magnitude of change was observed in Typic Rhodustalf profile than in Vertic Haplustalf soil profiles.

Table. 14a. Physico-chemical characteristics of Typic Rhodustalf at Korba

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.02	5.31	0.215	1.791	64.6	6.9	28.5	scl	1.55
15 -30	0.01	5.58	0.286	0.417	63.6	2.9	33.5	scl	1.55
30 - 45	0.01	5.87	0.243	1.083	62.1	8.4	29.5	scl	1.56
45 - 60	0.01	5.98	0.157	1.500	67.1	6.9	26.0	scl	1.56
60 - 90	0.01	6.46	0.415	1.042	69.6	3.4	27.0	scl	1.58
90 -120	0.02	7.26	0.143	1.500	69.6	6.4	24.0	scl	1.61

Table. 14b. Water soluble and exchangeable cations and cation exchange capacity of Typic Rhodustalf at Korba

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	1.0	0.4	4.9	Trace	4.80	3.60	1.04	0.16	13.20
15 -30	0.8	1.4	5.0	Trace	5.60	4.00	1.04	0.08	14.60
30 - 45	1.8	0.4	5.0	Trace	6.40	5.20	1.04	0.08	17.20
45 - 60	1.0	1.2	4.9	Trace	6.40	2.80	1.04	0.04	13.10
60 - 90	2.2	0.0	4.9	Trace	7.00	2.40	1.00	0.04	13.10
90 -120	1.6	0.2	4.8	Trace	5.80	2.40	1.04	0.04	12.90

Table. 14c. Hydraulic characteristics of Typic Rhodustalf at Korba

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	2.741	0.280	0.153	0.072	0.081	1.215
15 -30	1.601	0.330	0.176	0.098	0.078	1.170
30 - 45	2.442	0.278	0.157	0.078	0.079	1.185
45 - 60	2.457	0.239	0.124	0.063	0.061	0.915
60 - 90	2.451	0.255	0.149	0.070	0.079	4.470
90 -120	2.801	0.260	0.135	0.065	0.070	4.050

Table 14d. Micronutrient availability in Typic Rhodustalf at Korba

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	12.8	22.6	0.58	0.62
15 -30	15.4	35.2	0.72	0.64
30 - 45	12.6	37.2	0.54	0.64
45 - 60	14.4	29.6	0.68	0.38
60 - 90	12.6	32.4	1.42	0.68
90 -120	6.8	18.6	1.16	0.68

Table. 15a. Physico-chemical characteristics of Typic Haplustalf at Surguja

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.01	5.43	0.586	2.625	43.0	23.5	33.5	cl	1.42
15 -30	0.01	5.78	0.186	1.750	35.5	21.5	43.0	c	1.43
30 - 45	0.01	5.90	0.217	1.042	34.0	20.0	46.0	c	1.44
45 - 60	0.01	6.10	0.200	0.625	37.0	16.0	47.0	c	1.45
60 - 90	0.01	5.88	0.143	0.458	38.0	18.5	43.5	c	1.47
90 -120	0.01	5.78	0.073	0.958	38.0	17.5	44.5	c	1.50

Table. 15b. Water soluble and exchangeable cations and cation exchange capacity of Typic Haplustalf at Surguja

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	
0 - 15	0.4	0.4	4.0	Trace	5.60	3.60	1.04	0.08	12.30
15 -30	1.8	0.8	4.0	Trace	7.20	3.40	1.10	0.16	14.30
30 - 45	2.2	0.4	3.7	Trace	6.40	4.80	1.04	0.20	15.30
45 - 60	0.6	1.8	3.7	Trace	7.80	3.40	1.10	0.20	15.90
60 - 90	1.2	1.4	3.7	Trace	7.60	2.40	1.10	0.20	14.50
90 -120	1.6	0.8	4.0	Trace	7.40	2.60	1.10	0.16	14.80

Table. 15c. Hydraulic characteristics of Typic Haplustalf at Surguja

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3}) at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	1.941	0.390	0.312	0.072	0.240	3.600
15 -30	0.671	0.401	0.335	0.122	0.213	3.195
30 - 45	0.512	0.439	0.380	0.135	0.245	3.675
45 - 60	0.411	0.472	0.404	0.145	0.259	3.885
60 - 90	0.321	0.412	0.364	0.123	0.241	10.92
90 -120	0.451	0.429	0.366	0.132	0.234	10.98

Table 15d. Micronutrient availability in Typic Haplustalf at Surguja

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	138.0	19.2	0.80	1.88
15 -30	29.6	3.9	0.56	1.16
30 - 45	15.0	3.8	0.60	0.78
45 - 60	8.30	3.5	1.12	0.64
60 - 90	6.3	3.1	0.70	0.62
90 -120	6.6	3.4	0.90	0.54

Table. 16a. Physico-chemical characteristics of Typic Haplustalf at Dantewada

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.04	4.86	0.477	0.833	26.0	31.0	43.0	c	1.36
15 -30	0.02	5.11	0.402	1.042	22.5	28.0	49.5	c	1.40
30 - 45	0.02	5.18	0.402	1.083	22.0	25.0	53.0	c	1.42
45 - 60	0.01	5.20	0.104	0.792	21.0	22.0	57.0	c	1.43
60 - 90	0.01	5.05	0.253	0.208	19.5	23.0	57.5	c	1.45
90 -120	0.01	5.60	0.179	0.208	22.5	25.5	52.0	c	1.45

Table. 16b. Water soluble and exchangeable cations and cation exchange capacity of Typic Haplustalf at Dantewada

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	1.8	0.0	3.7	Trace	4.80	3.20	1.00	0.16	10.40
15 -30	1.2	0.4	4.0	Trace	8.40	3.40	0.96	0.16	13.90
30 - 45	1.8	1.6	4.8	Trace	8.40	3.20	0.96	0.16	14.10
45 - 60	4.2	0.0	3.7	Trace	8.60	3.80	0.90	0.16	15.00
60 - 90	1.2	1.0	4.0	Trace	8.40	4.60	0.90	0.16	15.50
90 -120	2.0	0.0	3.7	Trace	8.20	4.60	0.90	0.16	14.10

Table. 16c. Hydraulic characteristics of Typic Haplustalf at Dantewada

Soil depth (cm)	Ks (cm h^{-1})	θs ($cm^3 cm^{-3}$)	θ($cm^3 cm^{-3}$) at 0.033 MPa	θ($cm^3 cm^{-3}$) at 1.5 MPa	Available water content ($cm^3 cm^{-3}$)	Total water capacity (cm)
0 - 15	0.811	0.513	0.363	0.172	0.191	2.865
15 -30	0.722	0.564	0.372	0.220	0.152	2.280
30 - 45	0.556	0.583	0.407	0.241	0.166	2.490
45 - 60	0.351	0.591	0.421	0.244	0.177	2.655
60 - 90	0.331	0.598	0.433	0.252	0.181	12.990
90 -120	0.302	0.577	0.389	0.230	0.159	11.670

Table 16d. Micronutrient availability in Typic Haplustalf at Dantewada

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	60.4	127.0	0.44	2.30
15 -30	42.8	67.2	0.22	2.00
30 - 45	36.0	45.4	0.46	2.00
45 - 60	32.0	41.6	0.38	1.44
60 - 90	30.6	33.0	0.46	1.22
90 -120	34.4	41.2	0.42	1.44

Table: 17. Water storage capacity of the Alfisol profiles

Profile No	Name of the sub-group	Profile water Storage capacity (cm m^{-1} depth)	Category for profile water capacity
8	Typic Rhodustalf	7.56	Low
9	Typic Haplustalf	23.93	Very high
10	Typic Haplustalf	17.31	High

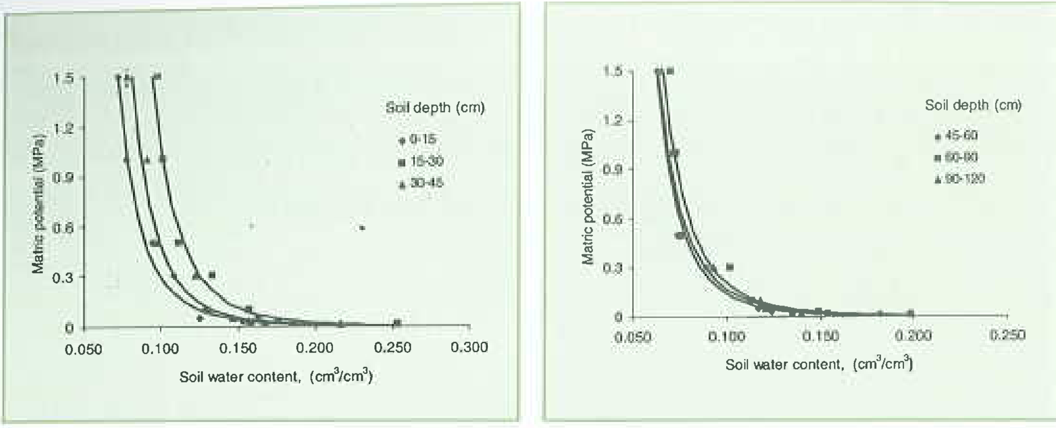

Fig. 9a. Matric potential as a function of soil water content in Typic Rhodustalf at Korba

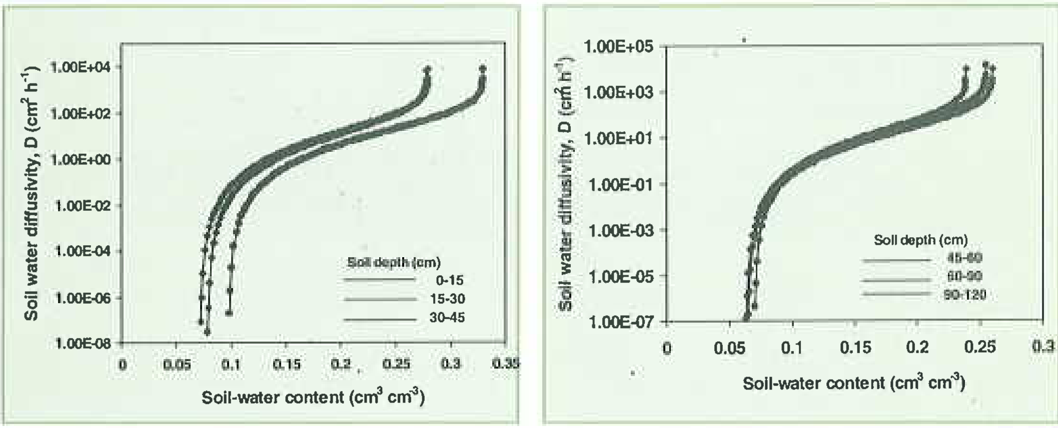

Fig. 9 b. Soil water diffusivity as a function of water content in Typic Rhodustalf at Korba

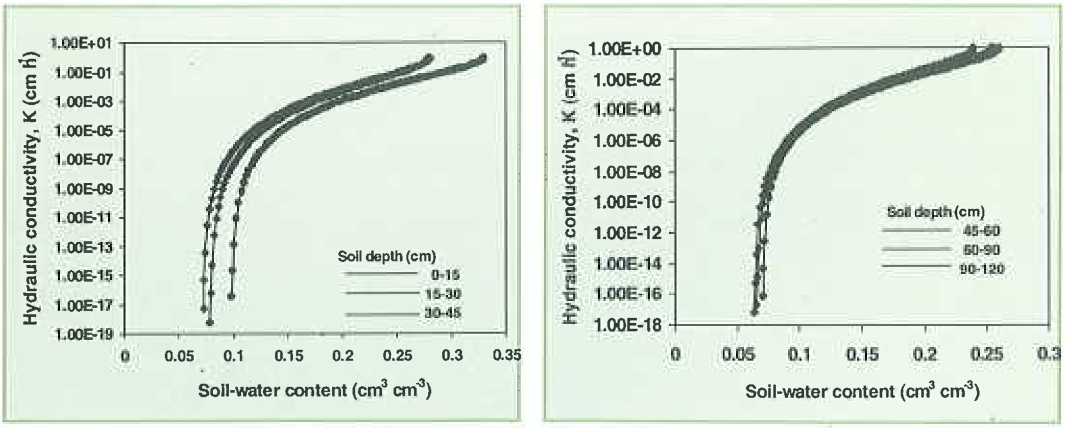

Fig. 9 c. Hydraulic conductivity as a function of water content in Typic Rhodustalf at Korba

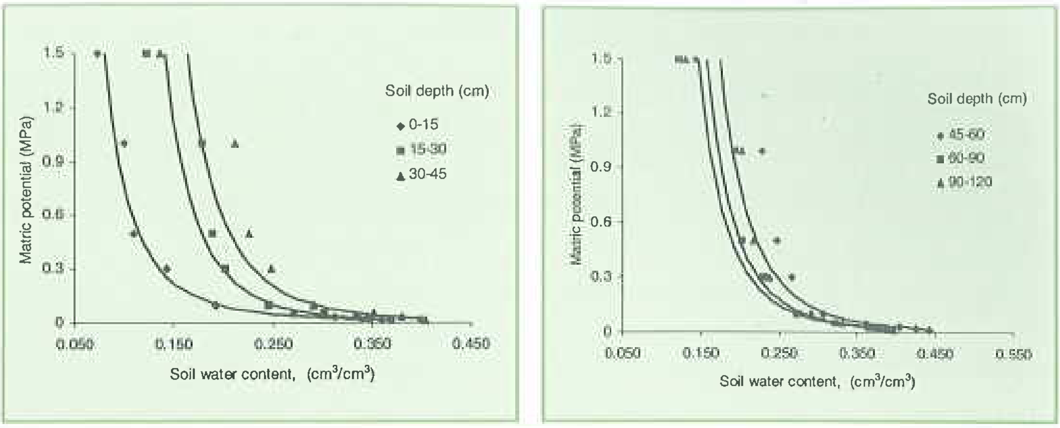

Fig. 10a. Matric potential as a function of soil water content in Typic Haplustalf at Surguja

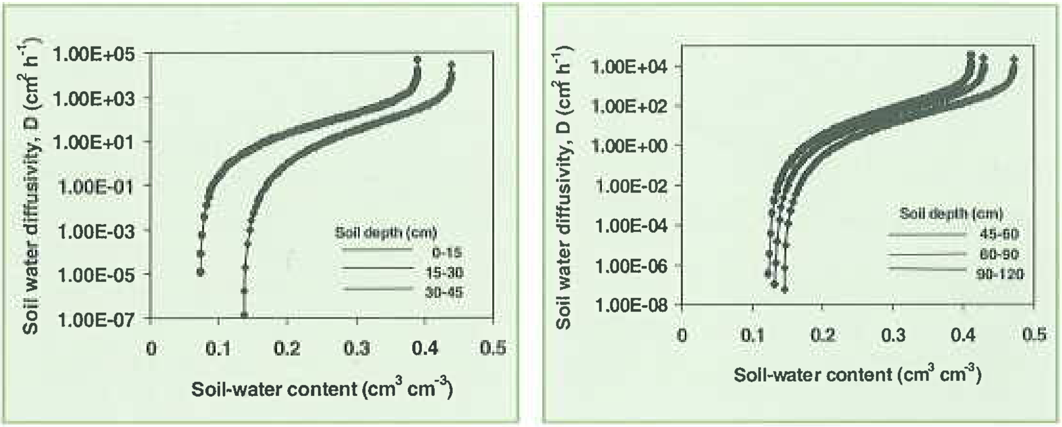

Fig. 10 b. Soil water diffusivity as a function of water content in Typic Haplustalf at Surguja

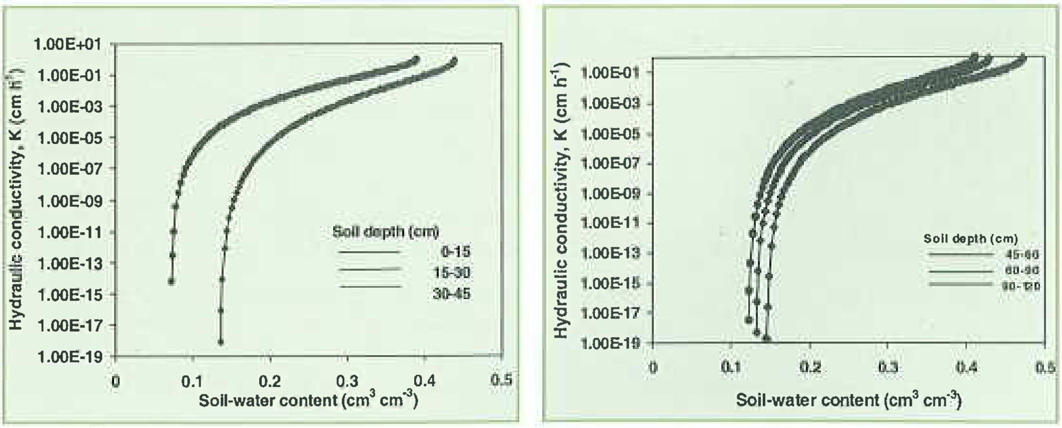

Fig. 10 c. Hydraulic conductivity as a function of water content in Typic Hapustalf at Surguja

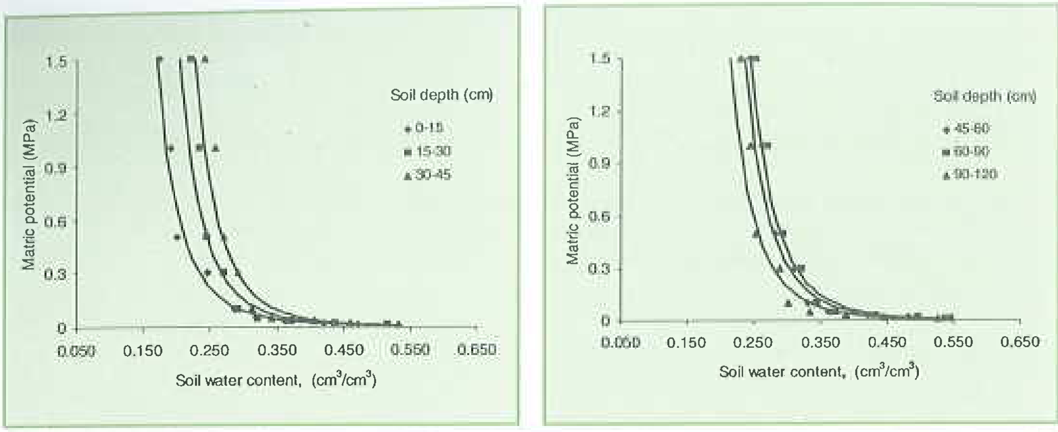

Fig. 11a. Matric potential as a function of soil water content in Typic Haplustalf at Dantewada

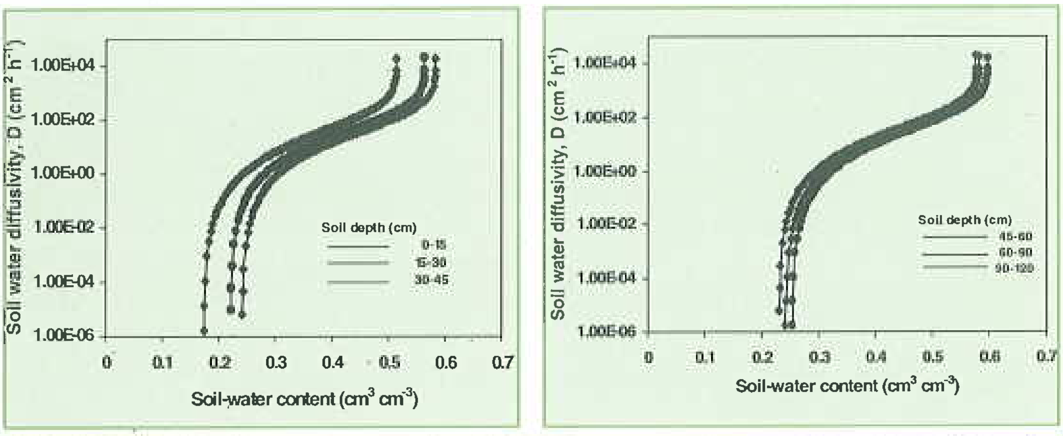

Fig. 11 b. Soil water diffusivity as a function of water content in Typic Haplustalf at Dantewada

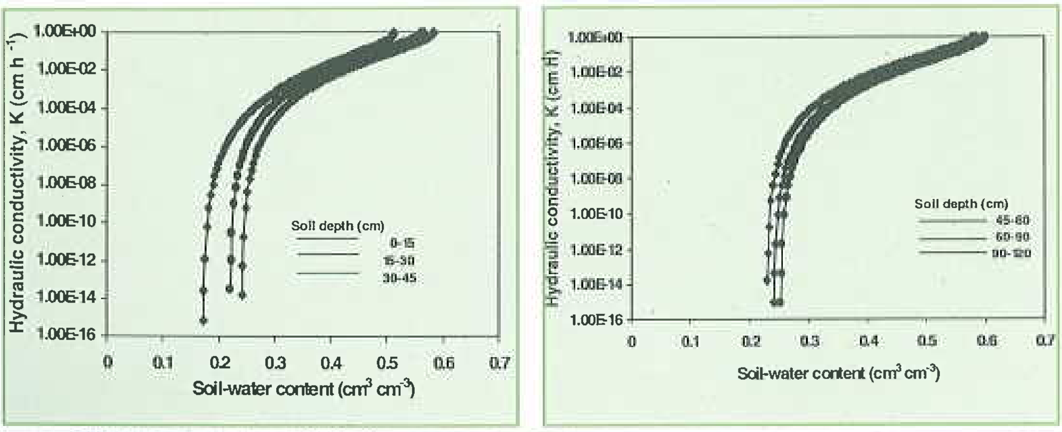

Fig. 11 c. Hydraulic conductivity as a function of water content in Typic Hapustalf at Dantewada

4.4 Soil Order: MOLLISOL

Soils under Mollisol order are characterized by a mollic epipedon, or a surface horizon, which is thick, dark, and dominated by base-forming cations such as Ca^{2+} and Mg^{2+}. These soils may have an argillic, nitric, albic, or cambic horizon, but not an oxic or spodic one. The surface horizon generally has granular or crumb structure, largely resulting from the organic matter present, that are not hard when the soils are dry. Most of the soils under Mollisol have developed under grass vegetation. The high native fertility of Mollisol makes them more productive soils. High native organic matter releases sufficient nitrogen and other nutrients to produce high crop yields even without fertilization. The dominating sub-group is Lithic Haplustoll.

4.4.1 Physico-chemical and hydrological characteristics

Physico-chemical and hydrological characteristics of the Mollisol are presented in Table 18. Lithic Haplustoll was sandy clay loam to clay in texture with clay content ranging from 27.8 to 41.8 per cent. Bulk density varied from 1.331 to 1.441 Mg m^{-3}. The soil was free from any salt problem and $pH_{2.5}$ varied from 5.83 to 6.28. Organic carbon content was 0.501 per cent in 0-15 cm soil layer and 1.073 per cent in deeper layers. It indicates that due to soil and water erosion organic carbon washed away from surface layers. $CaCO_3$ content ranged from 0.500 to 0.958 per cent, indicating non-calcareous nature of the soil.

Cation exchange capacity varied from 13.5 to 21.40 cmol kg^{-1}. Exchangeable cation, calcium and magnesium ranged from 5.40 to 10.80 and 4.00 to 7.00 cmol kg^{-1}, respectively. Exchangeable calcium and magnesium were higher than sodium and potassium. But in case of water soluble cations sodium was higher than calcium, magnesium and potassium, where it ranged from 3.7 to 4.0 me L^{-1}.

Data on DTPA-extractable Fe, Mn, Zn and Cu in Lithic Haplustoll profile of Jashpur are presented in Table 18d. The profile had very high level of Fe from surface to subsurface layers. Available Zn and Cu contents were also high in this profile.

Saturated hydraulic conductivity varied from 0.871 cmh^{-1} in 0-15 cm soil layer to 0.361 cmh^{-1} in 90-120 cm soil layer. Higher water retention at 0.033 and 1.5 MPa, available water content and total water capacity was observed in deeper soil layers. Profile water storage capacity in this sub-group was very high; it was measured at 24.35 cmm^{-1}. Data on soil-water diffusivity and hydraulic conductivity in the soil as a function of water content is presented in Fig. 12b and 12c, respectively.

Table. 18a. Physico-chemical characteristics of Lithic Haplustoll at Jashpur

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.01	5.83	0.501	0.917	58.6	13.6	27.8	scl	1.33
15 -30	0.01	6.14	1.073	0.583	49.6	16.1	34.3	scl	1.33
30 - 45	0.02	6.00	1.073	0.667	46.1	16.1	37.8	sc	1.41
45 - 60	0.01	6.06	0.858	0.500	39.1	21.6	39.3	cl	1.43
60 - 90	0.01	5.92	0.644	0.958	39.1	23.1	37.8	cl	1.43
90 -120	0.02	6.28	0.644	0.667	39.6	18.6	41.8	c	1.44

Table. 18b. Water soluble and exchangeable cations and cation exchange capacity of Lithic Haplustoll at Jashpur

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	1.6	0.4	3.7	Trace	5.40	4.00	1.14	0.20	13.50
15 -30	1.8	2.6	4.0	Trace	6.80	4.40	1.12	0.28	14.80
30 - 45	1.6	3.4	4.0	Trace	8.40	6.80	1.10	0.28	18.40
45 - 60	2.2	1.8	4.0	Trace	9.80	6.20	1.10	0.36	19.30
60 - 90	2.0	2.6	4.0	Trace	8.40	6.20	1.12	0.36	18.30
90 -120	2.8	2.2	4.0	Trace	10.80	7.00	1.12	0.28	21.40

Table. 18c. Hydraulic characteristics of Lithic Haplustoll at Jashpur

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	0.871	0.318	0.243	0.082	0.161	2.415
15 -30	0.723	0.482	0.361	0.139	0.222	3.330
30 - 45	0.614	0.518	0.404	0.155	0.249	3.735
45 - 60	0.451	0.533	0.438	0.160	0.278	4.170
60 - 90	0.462	0.526	0.423	0.156	0.267	12.690
90 -120	0.361	0.543	0.442	0.173	0.269	13.260

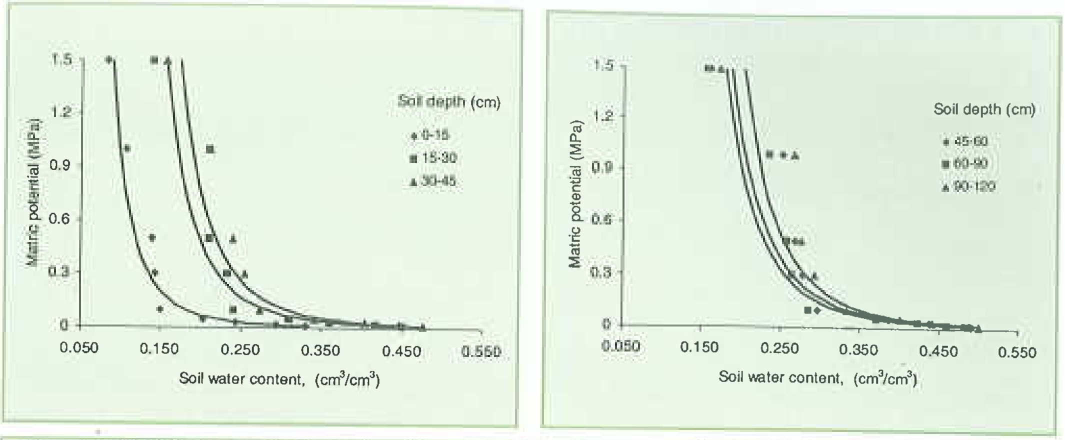

Fig. 12a. Matric potential as a function of soil water content in Lithic Haplustoll at Jashpur

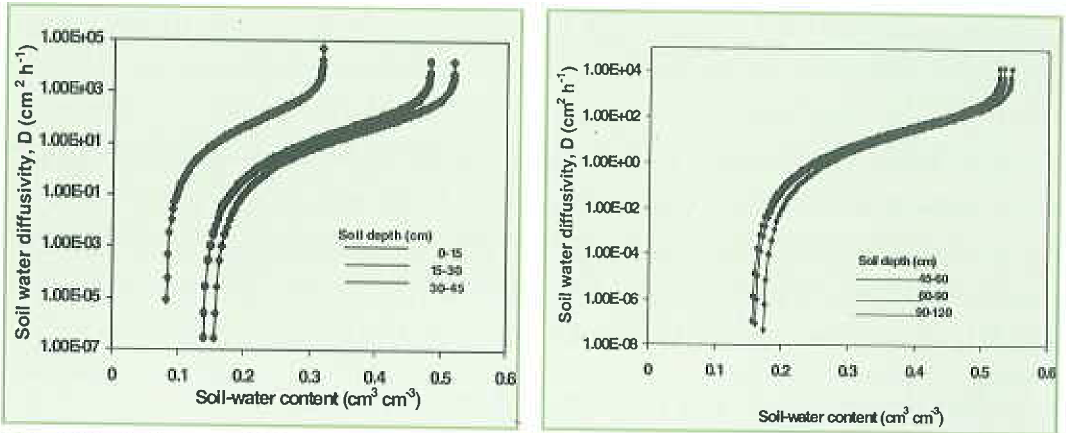

Fig. 12 b. Soil water diffusivity as a function of water content in Lithic Haplustoll at Jashpur

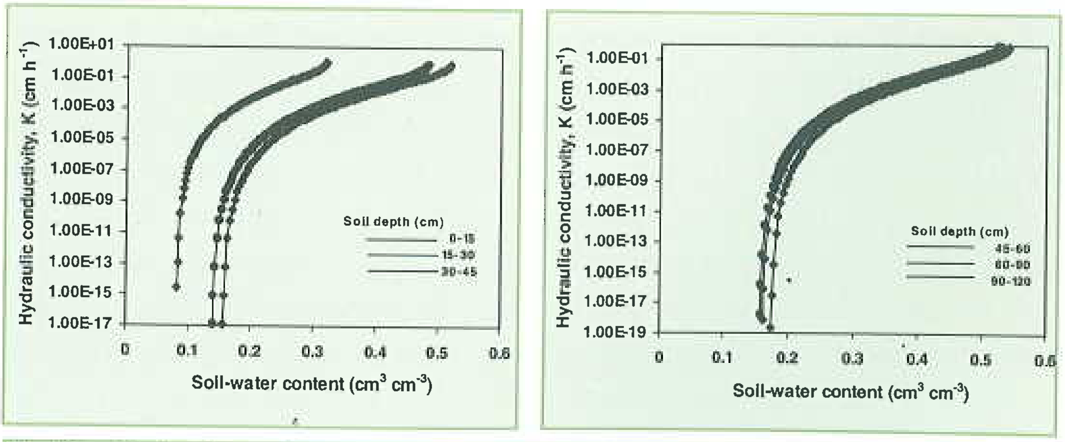

Fig. 12 c. Hydraulic conductivity as a function of water content in Lithic Haplustoll at Jashpur

Table 18d. Micronutrient availability in Lithic Haplustoll at Jashpur

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	136.2	34.0	1.50	1.30
15 -30	165.6	17.5	0.76	1.20
30 - 45	158.4	48.4	1.56	1.86
45 - 60	179.6	31.2	1.00	2.10
60 - 90	142.4	25.0	1.00	2.04
90 -120	84.6	29.6	0.78	1.82

4.5. Soil Order: VERTISOL

Soils of this order are tropical black with tremendous swell-shrink behaviour, deep (> 50cm) with high base saturation and dominated by smectite type of clay minerals. These soils swell on wetting and shrink on drying, which induces development of wide, deep cracks and mostly angular blocky structure. The cracking, followed by filling of cracks and swelling, results in the development of 'galgai micro-relief. They are dominantly observed on lower topographic positions or on flat terrain at the foot of the gentle slopes. They are mostly neutral to alkaline in reaction and fertile with high base status. In Chhattisgarh, there are two sub-groups under Vertisols, i.e. Chromic Haplustert and Typic Haplustert

4.5.1 Physico-chemical and hydrological characteristics

Physico-chemical and hydrological properties of Vertisols are presented in Table 19 to 21. Both sub-groups (Chromic Haplustert and Typic Haplustert) were clay in texture with clay content ranging from 45.0 to 50.70 per cent. Higher bulk density was observed in Chromic Haplustert, where it varied from 1.515 to 1.615 Mgm^{-3}. In Typic Haplustert it ranged from 1.373 to 1.542 Mgm^{-3}. Bulk density increased with depth in both soil profiles. Generally pH increased with soil depth. In 0-15 cm soil layer $pH_{2.5}$ values of Chromic Haplustert and Typic Haplustert were 7.2 and 7.3, respectively. In 90-120 cm soil depth, it was 7.78 and 8.08, in the same soil profile. Data on electrical conductivity showed that both the sub-groups were free from any salinity problem. In general both the sub-groups were low in organic carbon content (OC). OC content varied from 0.176 to 0.772 per cent. Higher OC content (0.772 %) was observed in 0-15 cm soil layer of Typic Haplustert, while it was 0.176

per cent in the same layer of Chromic Haplustert. Higher $CaCO_3$ content was found in Chromic Haplustert, where it varied from 0.833 to 4.374 per cent, while in Typic Haplustert it varied from 0.333 to 0.958 per cent. Higher exchangeable calcium and magnesium in comparison to sodium and potassium were found in both the sub-groups. Exchangeable calcium and magnesium varied between 9.20 to 12.60 and 5.20 to 9.80 meL^{-1}, respectively. Cation exchange capacity varied between 19.10 to 24.20 cmol kg^{-1} in Chromic Haplustert and 19.20 to 23.50 cmol kg^{-1} in Typic Haplustert. Higher quantity of water soluble sodium in comparison to calcium, magnesium and potassium was found in both sub-groups.

Data on DTPA-extractable Fe, Mn, Zn and Cu in Chromic Haplustert profile of Jangir are presented in Table 19d and Typic Haplustert profile of Bilaspur are given in Table 20d. Levels of Fe and Mn were adequate in both the soil profiles. Zn availability was much more in Chromic Haplustert than in Typic Haplustert profile.

Data on saturated hydraulic conductivity (Ks), moisture retention at saturation, 0.033 and 1.5 MPa, available water content and total water capacity are presented in Table 19c and 20c. Very low saturated hydraulic conductivity (0.035 to 0.102 cmh^{-1}) was observed in Chromic Haplustert. In Typic Haplustert it varied between 0.141 to 0.322 cmh^{-1}. Soil-water retention characteristics (ψ-θ relationship) of the soils are presented in Fig 13a and 14a. At 0.033 MPa, water retention varied from 0.359 to 0.401 cm^3cm^{-3} in Chromic Haplustert and 0.387 to 0.467 cm^3cm^{-3} in Typic

Table. 19a. Physico-chemical characteristics of Chromic Haplustert at Janjgir

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.09	7.20	0.176	0.833	30.2	23.6	46.2	c	1.52
15 -30	0.05	7.46	0.215	2.291	29.2	25.1	45.7	c	1.52
30 - 45	0.04	7.60	0.286	4.374	28.2	23.6	48.2	c	1.55
45 - 60	0.03	7.65	0.272	3.333	23.7	25.6	50.7	c	1.59
60 - 90	0.03	7.68	0.272	1.125	28.2	23.6	48.2	c	1.60
90 -120	0.08	7.78	0.272	1.583	29.2	21.1	49.7	c	1.62

Table. 19b. Water soluble and exchangeable cations and cation exchange capacity of Chromic Haplustert at Janjgir

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	2.0	2.4	4.0	Trace	9.20	5.20	1.04	0.28	20.70
15 -30	3.2	1.4	3.7	Trace	9.20	7.60	1.00	0.16	19.10
30 - 45	2.8	2.4	3.7	Trace	9.20	7.40	1.10	0.16	21.40
45 - 60	3.2	1.8	3.7	Trace	12.60	9.80	1.10	0.16	26.60
60 - 90	3.0	2.6	3.7	Trace	9.60	9.60	1.04	0.16	23.10
90 -120	2.8	2.0	3.6	Trace	9.60	8.40	1.10	0.16	24.20

Table. 19c. Hydraulic characteristics of Chromic Haplusterts at Janjgir

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3})at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	0.091	0.566	0.369	0.197	0.172	2.580
15 -30	0.102	0.533	0.359	0.191	0.168	2.520
30 - 45	0.052	0.573	0.381	0.199	0.182	2.730
45 - 60	0.041	0.599	0.401	0.208	0.193	2.895
60 - 90	0.048	0.554	0.374	0.198	0.176	11.220
90 -120	0.035	0.573	0.392	0.208	0.184	11.760

Table 19d. Micronutrient availability in Chromic Haplustert at Janjgir

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	16.5	9.6	9.0	1.68
15 -30	11.8	7.2	8.7	1.76
30 - 45	9.2	6.0	5.0	1.14
45 - 60	10.1	4.9	3.0	1.04
60 - 90	9.4	5.1	3.0	1.04
90 -120	10.6	5.8	1.6	1.12

Table. 20a. Physico-chemical characteristics of Typic Haplustert at Bilaspur

Soil depth (cm)	$EC_{2.5}$ (dS m^{-1})	$pH_{2.5}$	OC (%)	$CaCO_3$ (%)	Particle size analysis (%)			Textural class	Bulk density (Mg m^{-3})
					Sand	Silt	Clay		
0 - 15	0.08	7.30	0.772	0.583	33.6	18.4	48.0	c	1.37
15 -30	0.06	8.05	0.372	0.958	31.1	21.4	47.5	c	1.41
30 - 45	0.05	8.30	0.329	0.333	33.6	20.9	45.5	c	1.43
45 - 60	0.04	8.32	0.343	0.458	30.1	24.9	45.0	c	1.48
60 - 90	0.05	8.37	0.286	0.833	31.1	24.9	44.0	c	1.50
90 -120	0.05	8.08	0.286	0.625	30.6	23.3	45.5	c	1.54

Table.20b. Water soluble and exchangeable cations and cation exchange capacity of Typic Haplustert at Bilaspur

Soil depth (cm)	Water soluble cations (me L^{-1})				Exchangeable cations (cmol kg^{-1})				Cation exchange capacity (cmolkg^{-1})
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	
0 - 15	2.2	3.8	5.0	Trace	11.60	6.00	1.16	0.28	23.50
15 -30	2.8	3.0	5.0	Trace	10.60	6.40	1.14	0.16	22.10
30 - 45	2.6	2.8	5.0	Trace	9.60	5.80	1.10	0.16	19.20
45 - 60	1.6	4.0	5.0	Trace	10.60	5.60	1.30	0.16	21.30
60 - 90	1.8	3.2	4.9	Trace	9.60	5.20	1.04	0.16	20.50
90 -120	3.2	1.4	4.9	Trace	11.40	6.00	1.14	0.16	22.80

Table. 20c. Hydraulic characteristics of Typic Haplusterts at Bilaspur

Soil depth (cm)	Ks (cm h^{-1})	θs (cm^3 cm^{-3})	θ(cm^3 cm^{-3}) at 0.033 MPa	θ(cm^3 cm^{-3}) at 1.5 MPa	Available water content (cm^3 cm^{-3})	Total water capacity (cm)
0 - 15	0.240	0.702	0.467	0.237	0.230	3.450
15 -30	0.291	0.660	0.427	0.215	0.212	3.180
30 - 45	0.321	0.642	0.415	0.213	0.202	3.030
45 - 60	0.322	0.633	0.390	0.201	0.189	2.835
60 - 90	0.187	0.571	0.387	0.184	0.203	11.610
90 -120	0.141	0.634	0.415	0.204	0.211	12.450

Haplustert. At 1.5 MPa it varied between 0.172 to 0.184 cm^3cm^{-3} in Chromic Haplustert and from 0.184 to 0.237 cm^3cm^{-3} in Typic Haplustert. Slightly higher available water content was observed in Typic Haplustert (0.189 to 0.230 cm^3cm^{-3}) than in Chromic Haplustert (0.168 to 0.193 cm^3cm^{-3}). Similar types of results were also observed for total water capacity. Data on profile water capacity per meter depth are presented in Table 21. Very high profile water storage capacity was observed in Typic Haplustert and high profile water storage capacity was observed in Chromic Haplustert.

Data on soil-water diffusivity and hydraulic conductivity in the soils as a function of water content are presented in Fig 13 b to 14 b and 13c to 14c, respectively. In both the soils unsaturated hydraulic conductivity ($K\theta$) and soil-water diffusivity ($D\theta$), decreased with decrease in their water content. Low values of hydraulic conductivity and soil-water diffusivity were observed for both the sub-groups and the magnitude of the change in $K(\theta)$ and $D(\theta)$ with water content was also similar in both soil sub-groups.

Table 20d. Micronutrient availability in Typic Haplustert at Bilaspur

Soil depth (cm)	DTPA-Fe (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)
0 - 15	146.0	13.3	2.70	4.08
15 -30	23.4	3.14	0.88	1.42
30 - 45	17.0	2.6	1.06	1.48
45 - 60	11.4	2.0	0.68	1.22
60 - 90	11.2	1.9	0.58	1.26
90 -120	12.4	2.8	0.50	1.42

Table: 21.Water storage capacity of the Vertisol profiles

Profile No	Name of the sub-group	Profile water Storage capacity (cm m^{-1} depth)	Category for profile water capacity
12	Chromic Haplustert	17.85	High
13	Typic Haplustertu	20.70	Very high

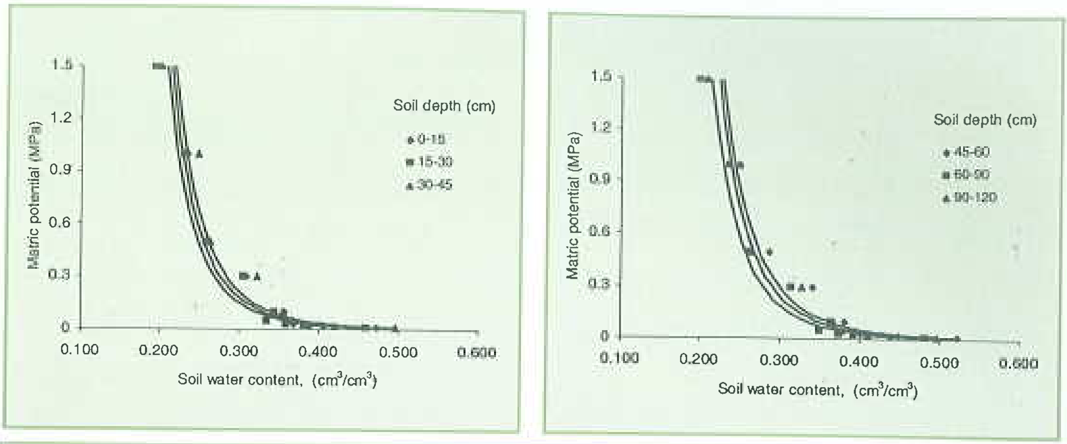

Fig. 13a. Matric potential as a function of soil water content in Chromic Haplustert at Janjgir

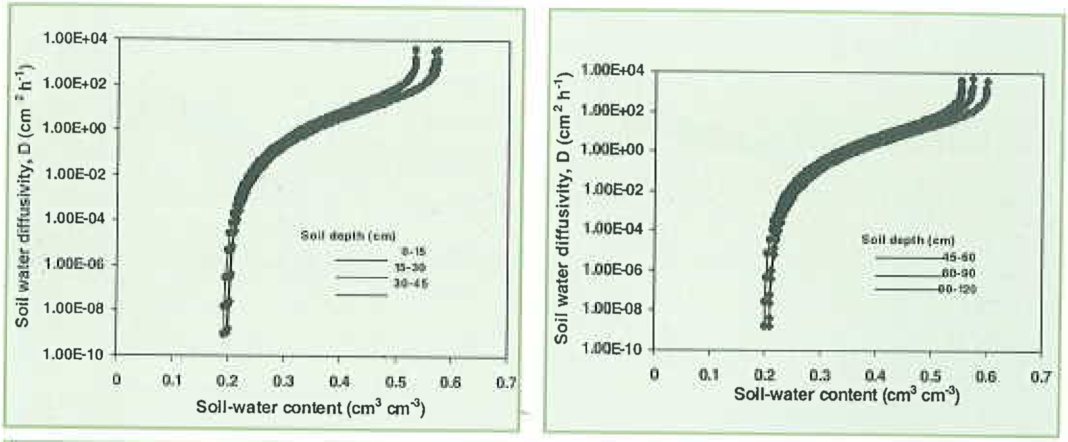

Fig. 13 b. Soil water diffusivity as a function of water content in Chromic Haplustert at Janjgir

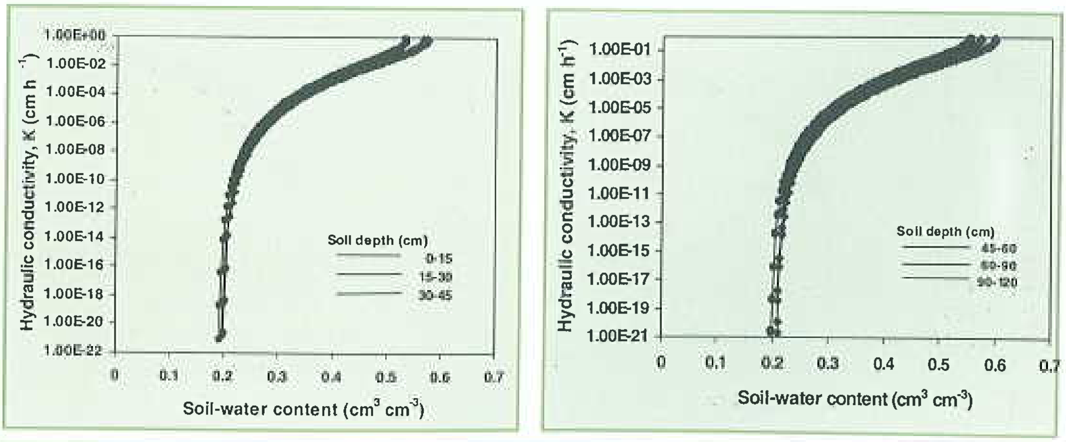

Fig. 13c. Hydraulic conductivity as a function of water content in Chromic Haplustert at Janjgir

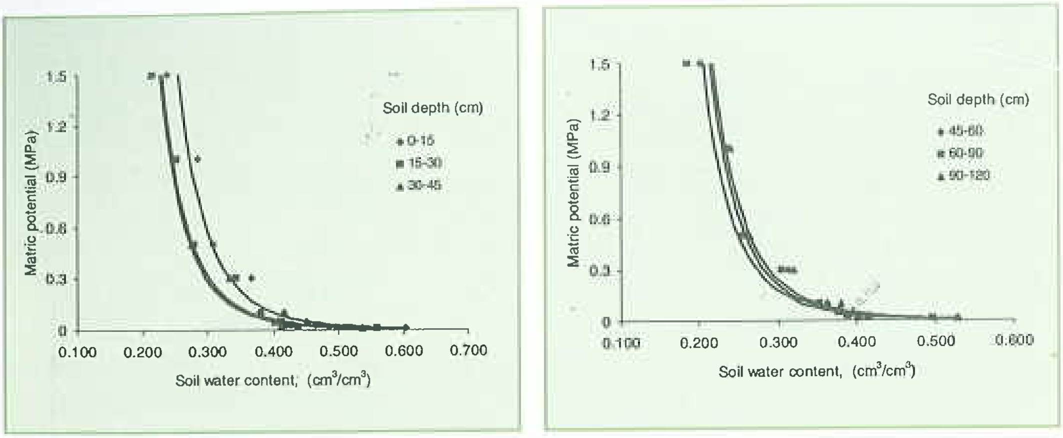

Fig. 14 a. Matric potential as a function of soil water content in Typic Haplustert at Bilaspur

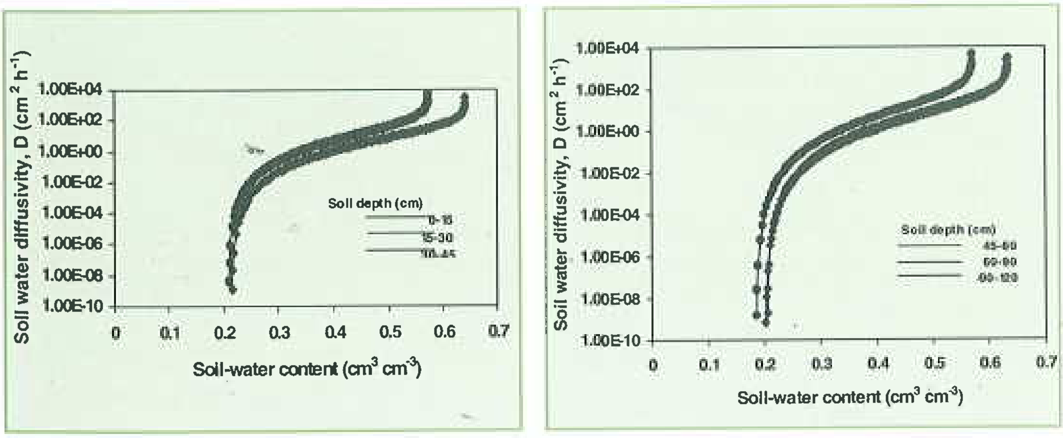

Fig. 14 b. Soil water diffusivity as a function of water content in Typic Haplustert at Bilaspur

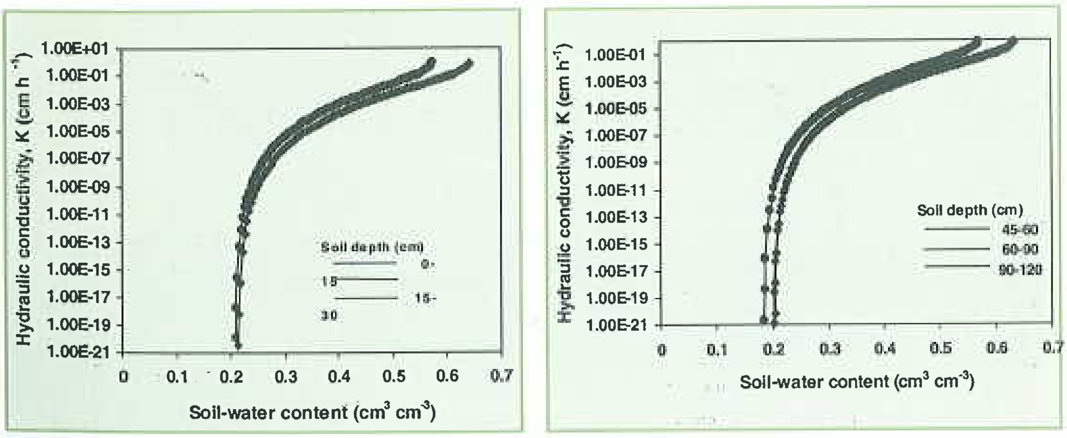

Fig. 14 c. Hydraulic conductivity as a function of water content in Typic Haplustert at Bilaspur

5. ERODIBILITY OF MAJOR SOIL SUB-GROUPS OF CHHATTISGARH

Soil erosion has been identified as a potential threat to sustainability of the livelihood system of the people in eastern India. Soil erosion by water is greatly influenced by erosivity and erodibility. While erosivity of soils depends on rainfall, soil erodibility broadly depends on soil properties, topographic features of land and management practices of land and crop. Erodibility of surface as well as sub-surface soils belonging to 5 orders and 9 sub-groups in Chhattisgarh was assessed by using erosion index.

Erosion indices of 9 soils at three different depths are presented in Table 22 to 24. Averaged over the depths, mean clay ratio was highest in Typic Rhodustalf and followed by Lithic Haplustoll, Typic Ustorthent, Typic Haplustept and the lowest

Table :22. Clay ratio of soil sub-groups of Chhattisgarh

Profile No.	Soil sub-group	Clay ratio			Mean
		Soil depth (cm)			
		0- 15	15 -30	30 –150	
1	Typic Ustorthent	1.83	2.19	1.77	1.93
2	Lithic Ustorthent	1.75	1.33	1.31	1.46
3	Typic Haplustept	2.01	1.80	1.62	1.81
4	Typic Haplustept	1.70	1.33	1.20	1.41
5	Typic Haplustept	1.60	1.33	1.19	1.37
6	Vertic Haplustept	1.08	0.87	0.84	0.93
7	Typic Haplustept	1.54	1.54	1.11	1.40
8	Typic Rhodustalf	2.51	1.99	2.78	2.43
9	Typic Haplustalf	2.05	1.33	1.21	1.53
10	Typic Haplustalf	1.33	1.02	0.83	1.06
11	Lithic Haplustoll	2.60	1.92	1.56	2.03
12	Chromic Haplustert	1.16	1.19	1.03	1.13
13	Typic Haplustert	1.08	1.11	1.22	1.14
Mean		1.71	1.46	1.40	
C D (P=0.05) to compare	soil sub-group means: 0.06 soil depth means: 0.02 sub-group x depth: 0.10				

Table:23. Dispersion ratio of soil sub-groups of Chhattisgarh

Profile No.	Soil sub-group	Dispersion ratio Soil depth (cm)			Mean
		0- 15	15 -30	30 –150	
1	Typic Ustorthent	73.78	74.95	69.81	72.85
2	Lithic Ustorthent	69.38	66.76	67.68	67.94
3	Typic Haplustept	87.72	86.61	82.20	85.51
4	Typic Haplustept	79.90	78.53	74.80	77.74
5	Typic Haplustept	76.52	79.41	76.86	77.60
6	Vertic Haplustept	71.44	64.24	64.86	66.85
7	Typic Haplustept	72.96	74.97	62.46	70.13
8	Typic Rhodustalf	75.14	75.82	76.34	75.77
9	Typic Haplustalf	69.12	59.53	68.23	65.63
10	Typic Haplustalf	70.47	64.06	60.55	65.03
11	Lithic Haplustoll	64.25	62.70	69.48	65.48
12	Chromic Haplustert	68.05	74.15	69.60	70.60
13	Typic Haplustert	73.80	74.17	76.79	74.92
Mean		72.50	71.22	69.97	

C D (P=0.05) to compare soil sub-group means: 0.92
soil depth means: 0.44
sub-group x depth: 1.56

in Vertic Haplustept. Highest dispersion ratio was found in Typic Haplustept and Typic Rhodustalf and the lowest was in Typic Haplustalf. Mean erosion index was highest in Typic Haplustept (42.10) and the lowest in Lithic Ustorthent.

5.1. Relationship between erosion index and other soil properties

Relationship of clay ratio, dispersion ratio and erosion index with salient properties of the soils was studied. Among various properties tested, silt and clay content, bulk density, organic carbon content and dispersion ratio showed significant relationship with the erosion index. Correlation co-efficient (r) values presented in Table 25 revealed that silt, organic carbon content and dispersion ratio have significant and positive relationship with erosion index. Relationship of erosion index with clay content and bulk density of the soils was found to be significant and negative. Negative relationship with clay and bulk density suggested that soil erodibility decreased with increasing clay content or bulk density of the soils.

Table 24: Erosion Index of soil sub-groups of Chhattisgarh

Profile No.	Soil sub-group	Erosion index			Mean
		Soil depth (cm)			
		0- 15	15 -30	30 –150	
1	Typic Ustorthent	28.98	30.01	26.54	28.51
2	Lithic Ustorthent	20.84	21.53	22.63	21.66
3	Typic Haplustept	43.86	42.54	39.90	42.10
4	Typic Haplustept	33.21	34.01	33.55	33.59
5	Typic Haplustept	33.66	32.32	32.59	32.86
6	Vertic Haplustept	28.38	23.57	24.77	25.58
7	Typic Haplustept	34.01	35.58	25.50	31.70
8	Typic Rhodustalf	24.61	24.90	24.72	24.74
9	Typic Haplustalf	26.82	18.51	22.00	22.44
10	Typic Haplustalf	28.02	24.33	21.66	24.67
11	Lithic Haplustoll	24.50	29.37	31.37	28.41
12	Chromic Haplustert	27.79	28.83	27.10	27.91
13	Typic Haplustert	35.98	34.35	35.24	35.19
Mean		29.05	27.99	27.04	

C D (P=0.05) to compare soil sub-group means: 0.09
soil depth means: 0.43
sub-group x depth: 1.56

Table: 25. Simple correlation coefficients among various soil properties.

	Sand (%)	Silt (%)	Clay (%)	Bulk density ($Mg\ m^{-3}$)	OC (%)	$CaCO_3$ (%)	Clay (%)	Dispersion Index	Erosion Index
Sand (%)	1.00								
Silt (%)	-0.81**	1.00							
Clay (%)	-0.86**	0.39**	1.00						
Bulk density ($Mg\ cm^{-3}$)	0.26**	-0.47**	0.01	1.00					
OC (%)	0.01	0.25**	-0.23**	-0.55**	1.00				
$CaCO_3$ (%)	0.08	0.02	-0.14	0.24**	-0.09	1.00			
Clay ratio	0.86**	-0.43**	-0.97**	0.04	0.19	0.15	1.00		
Dispersion Index	0.36**	-0.08	-0.50**	0.10	0.08	-0.01	0.43**	1.00	
Erosion Index	-0.05	0.34**	-0.23**	-0.20**	0.33**	-0.14	0.16	0.77**	1.00

** significant at P=0.05

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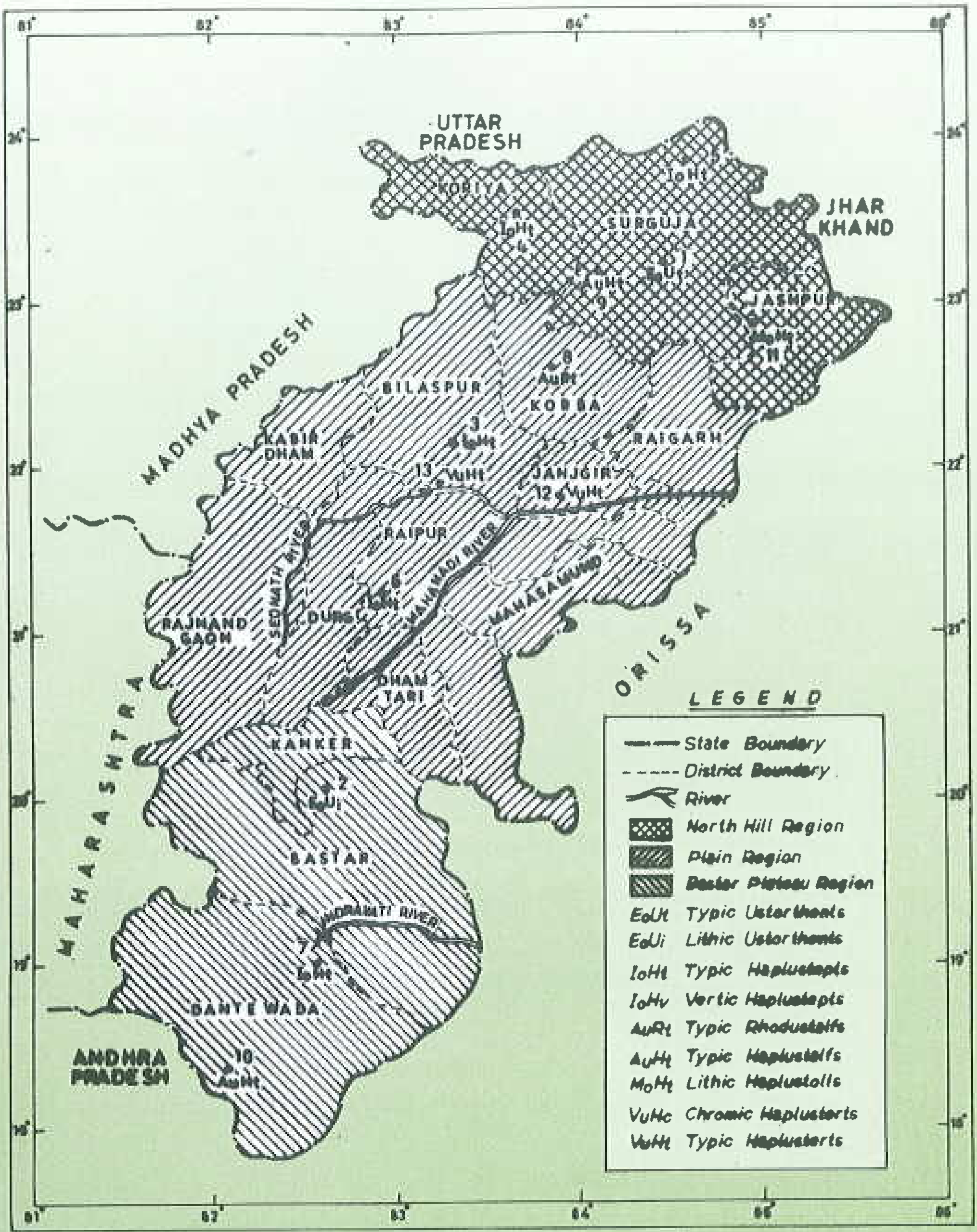

Fig. 15. Natural regions of Chhittisgarh

Based on rainfall pattern, temperature, soil type and existing cropping pattern Chhattisgarh State can be divided into three natural regions viz. North hill region; Plain region and Bastar plateau region (Fig. 15). The district-wise rainfall in different regions of Chhattisgarh during 1998-2002 and their normal average is presented in Table 26.

Table 26: District-wise Rainfall (mm) in Chhattisgarh

Districts	Normal Rainfall	1998	1999	2000	2001	2002
			North Hill Region			
Koriya	1410.9	1385.9	1380.7	1181.0	1483.2	926.3
Surguja	1493.2	1275.5	1344.3	1204.9	1651.7	1164.7
Jashpur	1726.6	1662.4	1612.6	1152.0	1591.3	1211.7
			Plain Region			
Raipur	1384.9	892.9	757.6	513.6	1321.2	725.6
Mahasamund	1549.5	812.1	920.6	613.0	1112.9	977.8
Dhamtari	1436.4	1040.2	1259.1	880.5	1474.9	770.3
Durg	1270.1	1448.2	1207.8	766.8	969.7	771.2
Rajnandgaon	1332.0	988.7	1089.0	879.7	1249.3	906.8
Kabardha	1108.8	1397.6	1326.6	814.3	1165.0	707.7
Bilaspur	1327.8	1375.0	916.5	674.5	1027.8	857.6
Janjgeer	1381.3	1268.2	1014.0	932.7	1272.9	930.8
Korba	1478.6	1424.7	2105.6	154.0	1410.5	1019.5
Raigarh	1639.2	1255.5	1177.3	1189.5	815.1	1261.6
			Bastar Plateau Region			
Bastar	1570.4	1066.5	1407.1	966.6	1737.5	901.6
Kanker	1371.0	1261.0	1375.4	1039.9	2159.3	990.5
Dantewada	1412.2	1361.8	1472.2	1443.4	1436.7	1147.3

Source : Fertiliser Association of India 2001.

During 2002-03 the net sown area in Chhattisgarh state was 47538000 ha (Table 27), out of which only 10785000 ha (23%) was irrigated.

Table 27: District-wise Land Utilization (area in '000 ha) in Chhattisgarh

Districts	Net Sown Area	Gross Sown Area	Net Irrigated Area	Gross Irrigated Area	% of Gross Irrigated Area to Gross Sown Area
North Hill Region					
Koriya	1028	1133	56	66	5.8
Sarguja	4849	5589	287	305	5.5
Jashpur	2521	2669	73	74	2.8
Plain Region					
Raipur	5481	6296	2863	3059	48.6
Mahasamund	2663	2818	576	580	20.6
Dhamtari	1338	1864	959	1314	70.5
Durg	5447	6939	1944	2420	34.9
Rajnandgaon	3587	4341	590	641	14.8
Kabardha	1844	2216	283	305	13.8
Bilaspur	3631	4537	1283	1433	31.6
Janjgir	2623	2989	1200	1689	56.5
Korba	1323	1414	56	72	5.1
Raigarh	2803	3046	350	409	13.4
Bastar Plateau Region					
Bastar	3495	3567	52	51	1.4
Kanker	2036	2126	163	163	7.7
Dantewada	2869	2908	50	50	1.7
Entire State					
Chhatisgarh	47538	54452	10785	12631	23.2

Source : Fertiliser Association of India 2001.

In Chhattisgarh state major sources of irrigation are canals, tube-wells, tanks and wells. In some parts irrigation is practices by some other sources. District-wise, source-wise irrigated area in different regions of Chhattisgarh is presented in Table 28.

Table 28: District/Source-wise Irrigated Area (in '00 ha) in Chhattisgarh

Districts	Canals	Tanks	Wells	Tube Wells	Other Sources	Gross Irrigated Area
			North Hill Region			
Koriya	40	2	11	*	12	65
Surguja	79	17	60	3	146	305
Jashpur	47	1	17	0	10	75
			Plain Region			
Raipur	2563	148	76	159	113	3059
Mahasamund	354	102	25	75	24	580
Dhamtari	1056	3	31	190	34	1314
Durg	1553	78	81	488	220	2420
Rajnandgaon	475	55	48	45	18	641
Kabardha	192	3	8	75	27	305
Bilaspur	1214	35	52	110	22	1433
Janjgeer	1464	60	23	123	19	1689
Korba	48	4	8	*	11	71
Raigarh	156	37	12	116	87	408
			Bastar Plateau Region			
Bastar	3	14	10	4	21	52
Kanker	74	39	12	12	26	163
Dantewada	5	32	2	*	10	49
			Entire State			
Chhatisgarh	9323	630	476	1401	800	12630

Source : Fertiliser Association of India 2001.

As discussed earlier, rice is the major crop of the state. Other than rice, wheat id the most irrigated crop followed by short duration pulses and sugarcane. In some parts particularly in Raigarh and Mahasamund districts of plain region groundnut is grown over a large area under irrigated conditions. District-wise, crop-wise irrigated area in different regions of Chhattisgarh is presented in Table 29.

Table 29: District and Crop wise Irrigated Area ('00 ha) in Chhattisgarh

Districts	Paddy	Maize	Wheat	Pulses	Gram	Sugarcane	Groundnut
North Hill Region							
Koriya	22	0	29	*	0	0	0
Surguja	39	*	156	3	*	13	0
Jashpur	43	0	9	*	*	*	0
Plain Region							
Raipur	2901	2	52	14	10	2	4
Mahasamund	527	0	14	4	*	1	10
Dhamtari	1288	0	4	2	*	0	0
Durg	2259	1	55	10	9	2	0
Rajnandgaon	584	*	25	3	1	*	0
Kabardha	257	-	20	2	2	21	0
Bilaspur	1361	0	36	2	*	1	0
Janjgeer	1624	0	18	4	1	1	9
Korba	50	0	4	*	0	0	0
Raigarh	319	0	9	8	1	6	24
Bastar Plateau Region							
Bastar	22	*	6	2	*	3	0
Kanker	138	7	3	*	*	0	0
Dantewada	45	*	*	*	0	0	0
Entire State							
Chhatisgarh	11479	10	440	54	24	50	47

Source : Fertiliser Association of India 2001.

Productivity of various crops in Chhattisgarh state is less than the National average (Table 30). Besides poor management practices, low yield levels attribute to low fertilizer consumption. Fertilizer consumption in the state is not low only but also imbalanced. Average fertilizer consumption of the entire state during 2002-03 and 2003-04 was 27.3:12.2:3.7 and 25.6:9.9:3.3 kg N:P_2O_5:K_2O/ha. Poor fertilizer consumption is one of the most important constraints, which are responsible for low water-use efficiency or input efficiency. District-wise consumption of N, P_2O_5 and K_2O in different regions of Chhattisgarh state is presented in Table 31

Table 30: District wise Current Average Yield (kg/ha) of Cereals in Chhattisgarh

Districts	Rice	Wheat	Maize
	North Hill Region		
Koriya	1502	1173	1526
Surguja	1128	1290	1601
Jashpur	1282	1440	1678
	Plain Region		
Raigarh	1065	1432	1845
Kawardha	1225	712	1457
Rajnandgawn	1195	722	1236
Durg	1383	710	1212
Raipur	1496	1146	1130
Mahasamund	1506	1727	1497
Dhamtari	1656	947	1588
Bilaspur	1533	940	1380
Korba	1222	984	1404
Janjgeer-Champa	1790	1552	1725
	Bastar Plateau Region		
Kanker	1289	1112	1848
Bastar	1190	1888	1992
Dantewada	936	1500	1646

Source : Chhatisgarh in Charts & Graphs 2001, Directorate of Economics & Statistics, Govt. of Chhatisgarh.

The climate of north hill region is sub-humid which is mild in summer and moderate in winter. The mean annual rainfall of the region is 1455 mm varying from 1248 to 1727 mm. Normally, the monsoon in this region onset by second week of June and recedes by third week of September. About 87 per cent of annual rainfall is received during June to September. The mean maximum and minimum temperatures of the region are 33.17 ^{0}C and 17.51^{0}C, respectively. Topography of the region is characterized as hilly and undulating having slopes of varying degrees (1-5%), Because of this type of topography, upland unbunded (Goda/Chawar

Table 31: District wise Consumption (kg/ha) of N, P_2O_5 and K_2O per Hectare in Chhattisgarh

Districts	2002-2003				2003-2004			
	N	P_2O_5	K_2O	NPK	N	P_2O_5	K_2O	NPK
North Hill Region								
Korea	13.0	5.7	1.2	19.9	6.7	3.8	0.8	11.2
Sarguja	14.5	7.4	1.9	23.8	15.5	6.0	1.3	22.8
Jashpur	6.1	2.6	0.4	9.2	2.7	6.9	0.5	10.1
Plain Region								
Raipur	35.6	19.8	5.8	61.3	35.5	19.0	6.4	60.9
Mahasamund	40.1	16.1	6.9	63.1	29.4	15.1	5.9	50.4
Dhamtari	60.2	26.4	11.4	97.9	54.9	17.6	6.5	79.0
Durg	24.0	12.0	5.4	41.4	24.1	10.3	4.4	38.9
Rajnandgaon	22.6	11.9	2.8	37.3	16.3	8.6	2.5	27.4
Kabirdham	23.1	11.9	2.2	37.2	18.0	7.1	2.2	27.2
Bilaspur	34.6	14.7	2.7	52.0	40.2	10.9	2.9	53.9
Janjgir	73.6	23.4	6.9	103.9	73.1	14.1	6.4	93.6
Korba	13.3	3.1	0.6	17.0	7.4	3.7	1.3	12.3
Raigarh	45.2	16.8	3.6	65.5	46.7	14.1	3.2	64.0
Bastar Plateau Region								
Kanker	17.6	9.1	3.0	29.7	17.8	7.8	3.3	28.9
Bastar	4.8	2.9	1.2	8.9	4.4	2.6	1.0	8.0
Dantewada	1.8	0.4	0.1	2.3	0.9	0.3	0.1	1.3
Chhatisgarh	27.3	12.2	3.7	43.3	25.6	9.9	3.3	38.8

Source : Fertiliser Association of India 2001.

'DAND'), upland bunded (Goda Chawar), low land (Chawar) and extremely low-land (Bahra) land situations are formed. The major crops of the region are paddy (47.8%), kodo-kutki (16.6%), maize (6.0%), mustard (3.2%), gram (2.1%) and sesamum (3.1%). Rice is grown under almost all land situations; kodo-kutki mostly grown in gravelly and skeletal soils and maize is grown on sloppy lands. Irrigation facilities are very limited and fertilizer consumption is also very low in this region.

The cropping intensity is 106 per cent. Poor soil fertility, severe soil erosion, high infiltration rate, poor irrigation facilities, frequent occurrence of drought, poor drainage condition in some areas and waterlogging in lowlands are main limiting factors for crop production in this region.

Soils of North hill region belong to Entisol, Inceptisol and Mollisol orders and the dominating sub-groups are Typic Ustorthent; Typic Haplustept; Typic Haplustalf and Lithic Haplustoll (profile No. 1,4,5,9 and 11). Physico-chemical and hydrological characteristics of these sub-groups are presented in Table No. 2, 6, 7, 12 and 14 and Fig. 2,5,6,10 and 12. The highest erosion index (EI) in 0-15 cm soil layer was observed in Typic Haplustept (33.21 to 33.66) followed by Typic Ustorthent (28.98) and Typic Haplustalf (26.82). Lowest EI of 24.50 was observed in Lithic Haplustoll. In 15-30 cm soil depth, the highest EI values (34.01 and 32.32) were observed in Typic Haplustept and lowest of 18.51 in Typic Haplustalf. In 30-150 cm soil depth, the highest EI of 33.55 and 32.59 was observed in Typic Haplustept and lowest of 22.0 was observed in Typic Haplustalf (Table. 21). Adoption of suitable soil and water conservation measures will be necessary to improve water-use efficiency in all the soils of this region. Use of organic materials like green manure, FYM, and FYM + green manure both will prove very effective for improving water-use efficiency and crop production in these soils. Profile water storage capacity of these soils indicated that Lithic Haplustoll and Typic Haplustalf have very high (24.35 and 23.93 cm/m depth) and Typic Ustorthent and Typic Haplustept have high (18.53 and 17.18 cm/m depth) water storage capacity. The ψ-θ relationship, hydraulic conductivity, soil-water diffusivity and profile water storage capacity of these soils suggested that application of medium to heavy irrigation at long intervals, however, may be practiced in Lithic Haplustoll and Typic Haplustalf for higher water-use efficiency without any adverse effect. Frequent irrigations using small amount of water each time will be required to improve use efficiency of water applied to Typic Ustorthent and Typic Haplustept sub-groups. In Lithic Haplustoll and Typic Haplustalf, cultivation of a second crop without irrigation is possible after rainy season provided it is sown immediately after harvest of *kharif* crop and in *kharif* season short duration high yielding rice variety is grown. In Typic

Ustorthent and Typic Haplustept a second crop without irrigation is possible either as *paira* crop or with mulching, otherwise at least one irrigation is required.

Technological interventions for Hill region

- Sesbania green manuring @ 40 kg seeds/ha proved to be highly beneficial in increasing the productivity of rice-wheat and other crops and cut-down nitrogen requirement by 30-40%.
- Use of FYM is a must for enhancing water and nutrient use efficiency in this region. Application of FYM@10t/ha has been observed to be the most effective for enhanced productivity and maintaining good soil health.
- Gram:Mustard intercropping in 2:2 arrangements has been observed to be highly remunerative in this region.
- Besides recommended doses of fertilizers, various crops responded positively to the application of zinc as zinc sulphate @20 kg/ha and improved yield levels by 12-20%.
- Paddy straw mulching @10t/ha with the coverage of 80-90% conserves considerable moisture in crops like groundnut, cotton and bring-down water requirement by 40-45% even during summer season.
- Adoption of suitable soil and water conservation measures such as bund terracing, bunding, contour cultivation, cover cropping and in-situ moisture conservation by various grasses improve water-use efficiency in all the soils of this region.

In plain region/zone the average rainfall varies from 1300 to 1600 mm. The rainfall is extremely erratic and the major precipitation occurs during July to August. The climate is warm and humid. The net irrigated area in the region is about 22 per cent of the net cultivated area. The net sown area is about 3395 thousand ha and the area sown more than once is about 1007 thousand ha. Canal system forms the major source of irrigation. The major crops of the region are rice (about 55.0%), lathyrus (12.7%), kodon-kutki (8.0%),, linseed (5.6%), wheat (5.0%), urd (1.35%), gram (1.65) and sugarcane (1%). Low fertility, low consumption of fertilizer, lack of irrigation facilities, heavy soils, waterlogging in early and drought in late stages of crop growth in rainy season are major production constraints of this region.

The soils of plain region belong to Inceptisols, Alfisols and Vertisols orders and dominating sub-groups are Typic Haplustept, Vertic Haplustept, Typic Rhodustalf, Chromic Haplustept and Typic Haplustert (profile No 3,6,8,12 and 13). Physico-chemical and hydrological characteristics of these sub-groups are presented in Table 5,8,11,16 and 17 and Fig 4, 7,9,13 and 14. Mean erosion index (EI) for Typic Haplustept, Vertic Haplustept, Typic Rhodustalf, Chromic Haplustert and Typic Haplustert (profile No. 3,6,8,12 and 13) are presented in Table 21. In 0-15 cm soil depth, the highest EI of 43.86 was observed in Typic Haplustept followed by Typic Haplustert (35.98) and Vertic Haplustept (28.38). The lowest EI of 24.61 was observed in Typic Rhodustalf. Similar types of observations were also recorded for 15-30 and 30-150 cm soil depth. Higher values of EI were observed for 0-15 cm soil depth than 15-30 and 30-150 cm. Adaptation of suitable soil and water conservation measures will be necessary to improve water-use efficiency and crop productivity in Typic Haplustept and Typic Haplustert sub-groups. *In-situ* conservation of water will be necessary to improve water-use efficiency in Vertic Haplustept, Chromic Haplustert and Typic Rhodustalf. Data on soil moisture retention characteristics, hydraulic conductivity, soil-water diffusivity and profile water storage capacity suggest that frequent irrigation using small amount of water each time will be required to improve use efficiency of water applied to Typic Rhodustalf. Drip or sprinkler irrigation, mulching, *in situ* conservation of water and application of organic material and proper bunding will prove useful to improve use efficiency of applied water and increase crop yield in this sub-group. Application of medium to heavy irrigation at long intervals, may be practiced in Typic Haplustept, Vertic Haplustept, Chromic Haplustert and Typic Haplustert for higher water-use efficiency without any adverse effect. In Vertic Haplustept and Typic Haplustert, cultivation of a second crop without irrigation is possible after rainy season provided it is sown immediately after the harvest of *kharif* crop. In Typic Haplustept and Chromic Haplustert sub-group a second crop without irrigation is possible either as a *paira* crop or with mulch. In Typic Rhodustalf second crop is not possible without irrigation. All the soil groups needed application of improved water management practices for achieving higher water-use efficiency and crop yields.

Technological interventions for Plain region

- Use of zero till seed-drill implement under optimum irrigation conditions increases the productivity of rice-wheat sequence by 15-17%.
- Application of 20kg $ZnSO_4$ per hectare along with recommended doses of NPK increases yield of rice by 10-12% and that of wheat by 15-20%.
- Rice-mustard and rice-gram observed to be better remunerative than rice-wheat by obtaining 3.5:1 B:C ratio on long-term basis. Summer cucurbit cab be succefully included in this system.
- Pomegranate can be irrigated by drip system at 60%PE on alternate day basis for higher productivity in the middle and tail ends of the command.
- Adopting sprinkler irrigation the water requirement of wheat could be reduced by about 50% with additional productivity of 20-25%.
- Irrigating tomato by drip produces 40-45 t/ha tomato fruit yield with 50-60% water saving.
- Planting sugarcane in paired–rows and adopting drip, one lateral for each pair at 80% PE, produces 110-125 t/ha cane yield with 40% water saving.
- Onion and potato crops can successfully be grown by sprinkler method and a net profit of Rs 50000-60000/ha can be obtained by achieving B:C ratio of 3.5-4.0.
- Under late sown conditions, wheat variety DL-803-3 observed to the highly water-use efficient and remunerative.
- Application of lime to soil or seed fortification wit lime and application of molybdenum @ 20 kg ammonium molybdate increases yield of soybean, gram, pigeonpea, black gram and sunflower by about 15-17% under optimum irrigation condition.

Bastar plateau region receives annual rainfall varying from 1200-1600 mm with maximum precipitation during July and August. Major area of this region (about 63%) is under forest cover. The net sown area is around 8.3 lakh ha and about 13.3 thousand ha is under irrigation. The major crops in the region during *kharif* are rice (about 65 %), kodo-kutki (18%), kulthi (4.5%), maize (3%) followed by ragi, jowar,urd and niger. In *rabi* season, only a small area (about 4%) of the net cropped area is under cultivation with rapeseed mustard, linseed, wheat, kulthi etc. Fertilizer consumption of the area is very low and cropping intensity is 129 %. Waterlogging in early and drought in later stage, undulating topography, high rainfall and excessive soil and water erosion are major production constraints of this region. Soils of Bastar plateau region belongs to Entisols, Inceptisols and Alfisols soil orders and dominating sub-groups are Lithic Ustorthent, Typic Haplustept and Typic Haplustalf (profile No. 2,7 and 10). Physico-chemical and hydrological characteristics are presented in Tables 3,9 and 13 and Fig. 3,8 and 11. In 0-15 and 15-30 cm soil depth the highest erosion index (35.58 and 34.01) was observed in Typic Haplustept followed by Typic Haplustalf (28.02 and 24.33) and lowest (21.53 and 20.84) was in Lithic Ustorthent (Table 21). Application of organic materials like FYM or compost to all the sub-groups and particularly Lithic Ustorthent will improve the water retention and water storage capacity of soil. Data on soil-water retention and available water content suggest that light and frequent irrigation and use of mulch will be useful to improve use efficiency of applied water in these sub-groups. The frequency of irrigation in these soils may be reduced through use of mulches. Use of drip or sprinkler irrigation will be effective for increasing water-use efficiency. Adaptation of suitable water management practices for *in-situ* conservation of water will be necessary for these sub-groups.. Application of suitable soil and water conservation measures are necessary particularly for Typic Haplustept sub-group. In Typic Haplustalf and Typic Haplustept, cultivation of a second crop without irrigation will be possible after rainy season provided it is sown immediately after the harvest of *kharif* crop or as a *paira* crop or with mulch. In Lithic Ustorthent second crop is not possible without irrigation.

Technological interventions for Bastar plateau region

- Under upland conditions, rice-moong (2:2) and rice-urid (1:1) Gives 20-25% extra benefit than the rice alone.
- Sesbania green manuring @ 40 kg seeds/ha proved to be highly beneficial in increasing the productivity of various crops and cut-down N requirement by 30-40%.
- Gram:Mustard intercropping in 2:2 pattern observed to be highly remunerative in Bastar region of Chhatisgarh.
- Pigeonpea can be successfully taken on the bunds of the rice fields and help in enhancing the productivity and ensures nutritional security.

7. PREDICTION OF WATER STORAGE CAPACITY OF THE SOIL PROFILES

Correlation studies were undertaken to identify important variables for establishing prediction equations of profile water storage capacity.

7.1 Correlation

Simple correlation coefficients (r) were worked out between sand, silt, clay, bulk densSimple correlation coefficients (r) were worked out between sand, silt, clay, bulk density, organic carbon, calcium carbonate and cation exchange capacity and water retained at field capacity, wilting point and available water capacity. Values of r are presented in Table 32. The results revealed that water content at field capacity and wilting point had a close relationship with clay (r = 0.77** and 0.84**, respectively) and cation exchange capacity (r=0.69** and 0.71**, respectively). They were significantly but negatively associated with sand content and bulk density indicating that with increase in value of either sand or bulk density or with decrease in clay content or silt content or cation exchange capacity, water content, of these soils at field capacity and wilting point, decreases. Coarse fraction (sand) has a close relationship with bulk density (r= 0.26**), while negative association exists between coarse fraction and finer fraction i.e. silt (r=0.81**) and clay (r=0.86**) of these soils. Available water showed positive correlation coefficient values with silt, clay, calcium carbonate and cation exchange capacity and negative values with sand and bulk density. These results are in good agreement with those of Patgiri *et al.* (1993), Yadav *et al.* (1995), Nagar *et al.* (1995) and Das and Dutta (1997). The moisture retention at field capacity, wilting point and available water in these soils were influenced by two sets of factors influencing in opposite direction (Table 32). While one set of factors, viz. silt, clay, organic carbon, calcium carbonate and cation exchange capacity influenced positively, the other set of factors, viz. sand and bulk density influenced negatively. Consequently, the available water content was also influenced by the same set of factors and in a similar manner.

Table : 32.Simple correlation coefficients

	Sand (%)	Silt (%)	Clay (%)	Bulk density (Mg m^{-3})	OC (%)	$CaCO_3$ (%)	CEC (cmolkg^{-1})	θ, at field capacity (cm^{3}cm^{-3})	θ, at wilting point (cm^{3}cm^{-3})	Available water capacity (cm^{3}cm^{-3})
Sand (%)	1.00									
Silt (%)	-0.81**	1.00								
Clay (%)	-0.86**	0.39**	1.00							
Bulk density (Mg cm^{-3})	0.26**	-0.47**	0.003	1.00						
OC (%)	0.006	0.25**	-0.23**	-0.55**	1.00					
$CaCO_3$ (%)	0.081	0.02	-0.14	0.24**	-0.09	1.00				
CEC (cmolkg^{-1})	-0.40**	0.17	0.48**	0.24**	-0.02	0.03	1.00			
θ, at field capacity (cm^{3}cm^{-3})	-0.82**	0.59**	0.77**	-0.23**	0.16	0.21**	0.69**	1.00		
θ, at wilting point cm^{3}cm^{-3})	-0.76**	0.41**	0.84**	-0.04	-0.08	0.21**	0.71**	0.87**	1.00	
Available water capacity (cm^{3}cm^{-3})	-0.58**	0.59**	0.39**	-0.39**	0.39**	0.14	0.40**	0.79**	0.38**	1.00

Table: 33. Linear regression co-efficient of various equations fitted to field capacity, wilting point and available water as a function of soil physico-chemical parameters

a				B				R^2
	Sand (%)	Silt (%)	Clay (%)	Bulk density (Mg m^{-3})	OC (%)	$CaCO_3$ (%)	CEC (cmolkg^{-1})	
For field capacity								
-3.456	0.036	0.039	0.041	-0.156	0.048	-0.017	0.010	0.894
2.473	-0.027	-0.023	-0.019	0.084	0.108	-0.015		0.757
4.192	-0.044	-0.040	-0.035	0.037	0.109			0.747
5.459	-0.054	-0.050	-0.045	-0.122				0.697
3.541	-0.036	-0.032	-0.028					0.689
0.705	-0.008	-0.003						0.688
0.596	-0.006							0.671
0.408	-0.005	-0.001					0.009	0.827
For wilting point								
-2.896	0.029	0.029	0.033	-0.077	-0.008	-0.011	0.007	0.860
0.970	-0.012	-0.011	-0.006	0.079	0.031	-0.010		0.728
2.159	-0.024	-0.023	-0.017	0.047	0.032			0.718
2.530	-0.027	-0.026	-0.020	0.001				0.708
2.533	-0.027	-0.06	-0.020					0.708
0.520	-0.007	-0.006						0.708
0.320	-0.004							0.580
0.331	-0.005	-0.004					0.006	0.833
For available water								
-0.056	0.007	0.010	0.008	-0.079	0.056	-0.005	0.004	0.556
1.503	-0.015	-0.012	-0.013	0.005	0.077	-0.005		0.499
2.034	-0.020	-0.017	-0.018	-0.010	0.077			0.495
2.929	-0.027	-0.024	-0.025	-0.122				0.409
1.007	-0.010	-0.006	-0.008					0.380
0.185	-0.001	0.003						0.380
0.277	-0.002							0.339
0.077	-0.001	0.004					0.003	0.444

7.2 Regression

Stepwise regression analysis was carried out to scan the effectiveness of the influence of variables, viz. sand, silt, clay, bulk density, organic carbon, calcium carbonate and cation exchange capacity on water content at field capacity, wilting point and available water. The regression coefficients and R^2 values are given in Table 33. All the variables put together accounted for a variation of 89.4, 86.0 and 55.6 per cent for the water retained at field capacity, wilting point and available water, respectively. Sand, silt, clay, bulk density, organic carbon and calcium carbonate accounted for 75.7 per cent variation in water retention at field capacity; sand, silt and cation exchange capacity together accounted for 82.7 per cent variation, and sand and silt alone accounted for 68.8 per cent variation. In case of wilting point, sand, silt, clay, bulk density, organic carbon and calcium carbonate together were responsible for 72.8 per cent variation; sand, silt and cation exchange capacity accounted for 83.3 per cent variation, and sand and silt alone accounted for R^2 values of 70.8 per cent. Inclusion of cation exchange capacity in the model improved the prediction values of retention both at field capacity as well as at wilting point. Similar types of observations were also made by Singh *et al*. (1988, 1992 and 2000) and Singh and Kundu (2000, 2001 and 2005) for alluvial soils.

For prediction of available soil-water, sand, silt and cation exchange capacity accounted for 44.4 per cent variation; sand, silt, clay, bulk density, organic carbon and calcium carbonate contributed to only 49.9 per cent; and sand and silt alone accounted for 38.0 per cent variation. Hence, available water can not be predicted as accurately as water content at field capacity and wilting point. It was better to estimate available water using the predicted values of field capacity and wilting point.

8. RESULTS OF PRACTICAL UTILITY AND RECOMMENDATIONS

- Soils of Chhattisgarh are developed by the actions and interactions amongst relief, parent materials and climate. Soils fall in 5 orders and 9 sub-groups.
- Entisol, Inceptisol, Alfisol, Mollisol and Vertisol soil orders constitute 19.5, 14.8, 39.0, 0.3, and 26.4% of the total cultivated area of the state, respectively.
- Typic Ustorthent, Lithic Ustorthent, Typic Haplustept, Vertic Haplustept, Typic Rhodustalf, Typic Haplustalf, Lithic Haplustoll, Chromic Haplustert and Typic Haplustert sub-groups constitute 1.6, 17.9, 9.5, 5.3, 6.1, 32.9, 0.3, 19.3 and 7.1% of the total cultivated area, respectively.
- Soils under Typic Ustorthent and Lithic Ustorthent sub-groups are sandy clay loam to clay in texture with dense sub-surface layers, slightly acidic in reaction, free from salt accumulation, low in organic carbon, non-calcareous in nature with medium cation exchange capacity. These are well-permeable soils with 10.6 to 18.5 cmm^{-1} profile water storage capacity.
- Soils of five sub-groups under Inceptisol order are sandy clay loam to clay in texture with relatively dense sub-surface layers, which can interfere with plant roots. Soils are slightly acidic to slightly alkaline in reaction with no appreciable salt concentration in the root zone, non-calcareous to moderately calcareous in nature with medium to high cation exchange capacity and high base saturation. Organic carbon content is relatively high. Some of the sub-groups show poor to moderate permeability and moderate transient-flow parameters. Soils retain relatively high amount of water at 0.33 and 1.5 MPa soil-water suction and can support plant growth to a relatively large period. These soils exhibit high to very high profile water storage capacity, thus, can be used for cultivating a variety of crops.
- Three sub-groups under Alfisol order are sandy clay loam to clay in texture with almost uniform bulk density throughout the profile. Soils are slight to moderately acidic in reaction with no salt accumulation either at surface or in root zone. These soils are non-calcareous in nature except Typic Haplustalf,

which contains >2% $CaCO_3$ in surface layer. These poor organic matter containing soils have high base saturation and low cation exchange capacity. Oils of Typic Rhodustalf sub-order are well permeable, while Typic Haplustalf are poor in permeability and transient-flow parameters. These soils exhibit low to very high profile water storage capacity.

- Soils of Lithic Haplustoll sub-group under Mollisol order are sandy clay loam in texture, slightly acidic with no salt deposition, medium in organic carbon content and non-calcareous in nature. Soils are characterized by high base saturation and moderate cation exchange capacity. These soils show good permeability and transmission characteristics with very high profile water storage capacity.
- Chromic Haplustert and Typic Haplustert sub-groups of Vertisol order are clay in texture with tremendous swell-shrink potential and high bulk density. Soils are neutral to slightly saline in reaction with moderate concentration of soluble salts. These soils are poor in organic matter, calcareous in nature, with very high base saturation and cation exchange capacity. Due to dominance of swelling clay minerals, soils are poor in permeability and transmission parameters. Soils show high to very high profile water storage capacity and can support crop production for a long period.
- Soils of Typic Rhodustalf sub-group were observed to be highly prone to erosion and dispersion, and warrants immediate attention for management in terms of efficient soil-water conservation.
- Erosion behaviour of soils of Chhattisgarh is mainly governed by silt + clay content, bulk density, organic carbon content and dispersion ratio. Thus, appropriate tillage practices and addition of organic manures and crop rotations hold key for sustainable management of these soils.
- Poor soil fertility, severe soil erosion, high infiltration, poor irrigation facilities, frequent drought occurrence and waterlogging in lowlands are the main limiting factors responsible for poor crop productivity of the state.

- In North-hill zone of the state, use of green manures and FYM is a must for enhancing crop yields and maintaining soil health. Frequent and light irrigation in check basins, border strips or furrows at optimum irrigation schedule can prove to be highly effective in improving water-use efficiency of different crops.
- Advancing sowing of *kharif* crops and adoption of early and medium duration varieties can ensure successful *rabi* cultivation on residual moisture without any irrigation. This practice can increase the cropping intensity in North-hill region to a considerable extent. Mulching and *paira* cropping are the other feasible alternatives for enhancing cropping intensity.
- In plain regions of Chhattisgarh state, *in-situ* rainwater conservation, water-use efficient crops and cropping sequences and appropriate land layouts can help in enhancing water-use efficiency of different crops. Timely sowing of *kharif* and *rabi* crops can reduce irrigation water requirements to a considerable extent. Zero tillage, *paira* cropping and mulching during *rabi* season are effective alternatives to raise crops on residual moisture.
- Soil-water retention and profile water storage capacity can be increased by addition of organic materials, green manuring and by adopting cropping sequences, which include pulses. Light and frequent irrigation with locally available mulch materials can improve water-use efficiency of different crops. For successful *rabi* cultivation, irrigation is a must. Without provision of irrigation, yields of *rabi* crops cannot be increased.
- Sesbania green manuring @ 40 kg seeds/ha proved to be highly beneficial in increasing the productivity of rice-wheat and other crops and cut-down nitrogen requirement by 30-40%.
- Use of FYM is a must for enhancing water and nutrient use efficiency in this region. Application of FYM@10t/ha has been observed to be the most effective for enhanced productivity and maintaining good soil health.
- Gram:Mustard intercropping in 2:2 arrangements has been observed to be highly remunerative in this region.

- Besides recommended doses of fertilizers, various crops responded positively to the application of zinc as zinc sulphate @20 kg/ha and improved yield levels by 12-20%.
- Paddy straw mulching @10t/ha with the coverage of 80-90% conserves considerable moisture in crops like groundnut, cotton and bring-down water requirement by 40-45% even during summer season.
- Adoption of suitable soil and water conservation measures such as bund terracing, bunding, contour cultivation, cover cropping and in-situ moisture conservation by various grasses improve water-use efficiency in all the soils of this region.
- Use of Pantnagar zero till seed-drill implement under optimum irrigation conditions increases the productivity of rice-wheat sequence by 15-17%.
- Application of 20kg $ZnSO_4$ per hectare along with recommended doses of NPK increases yield of rice by 10-12% and that of wheat by 15-20%.
- Rice-mustard and rice-gram observed to be better remunerative than rice-wheat by obtaining 3.5:1 B:C ratio on long-term basis. Summer cucurbit cab be succefully included in this system.
- Pomegranate can be irrigated by drip system at 60%PE on alternate day basis for higher productivity in the middle and tail ends of the command.
- Adopting sprinkler irrigation can brought down water requirement of wheat by about 50% with additional productivity of 20-25%.
- Irrigating tomato by drip produces 40-45 t/ha tomato fruit yield with 50-60% water saving.
- Planting sugarcane in paired–rows and adopting drip, one lateral for each pair at 80% PE, produces 110-125 t/ha cane yield with 40% water saving.
- Onion and potato crops can successfully be grown by sprinkler method and a net profit of Rs 50000-60000/ha can be obtained by achieving B:C ratio of 3.5-4.0.

- Under late sown conditions, wheat variety DL-803-3 observed to the highly water-use efficient and remunerative.
- Application of lime to soil or seed fortification wit lime and application of molybdenum @ 20 kg ammonium molybdate increases yield of soybean, gram, pigeonpea, black gram and sunflower by about 15-17% under optimum irrigation condition.
- Under upland conditions, rice-moong (2:2) and rice-urid (1:1) Gives 20-25% extra benefit than the rice alone.
- Sesbania green manuring @ 40 kg seeds/ha proved to be highly beneficial in increasing the productivity of various crops and cut-down N requirement by 30-40%.
- Gram:Mustard intercropping in 2:2 pattern observed to be highly remunerative in Bastar region of Chhatisgarh.
- Pigeonpea can be successfully taken on the bunds of the rice fields and help in enhancing the productivity and ensures nutritional security.
- Entisols (Lithic Ustorthent), Inceptisol and Alfisols (Typic Haplustalf) soils were found deficient in Zn availability. Application of Zn fertilizer to correct deficiency will be required to realize crop yield potentials in these soils.

9. REFERENCES

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Collection of profile soil samples from study sites