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Preface

Scientific management of land and water resources, both under irrigated and rainfed farming, requires a thorough understanding of physical, chemical and hydrological characteristics of the soils. This facilitates prevention of waterlogging, salinization and efficient use of available water resources through adoption of corrective 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 eastern region is predominantly rainfed. Although it receives high rainfall and has good groundwater resources, most of the farmers grow only one crop in rainy season and most of the fields remain fallow during postrainy season. In canal irrigated areas, use efficiency of applied water is very low. The region has good scope of irrigation expansion, use of groundwater and rainwater conservation. Information on physical, chemical and hydrological characteristics of eastern region soils of is scanty. 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 this technical bulletin. We sincerely hope information presented in this bulletin will be useful to the policy makers, scientists, scholars, developmental officials/agencies, farmers and others who are interested in management of soil and water resources in the eastern region of India.

The authors extend their sincere gratitude 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.

AUTHORS

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EXECUTIVE SUMMARY

- Area situated between latitudes of 17^0 N and 29^0 N and longitudes of 80^0 E and 97^0 E constitute the eastern region of India. The region includes eastern Uttar Pradesh, Bihar, Jharkhand, Assam, Chhattisgarh, Orissa and West Bengal states. Soils of eastern region fall in 6 orders, viz. Entisols, Inceptisols, Alfisols, Vertisols, Mollisols and Ultisols and 26 dominant subgroups. The region is dominated by Inceptisols covering approximately 34 mha area. Alfisols covers approximately 20 mha area, Entisols 14.5 mha and Vertisols about 3 mha area of the eastern region.

- The dominant soil subgroups of the eastern region are: Vertic Haplaquept, Aeric Haplaquept, Typic Tropaquept, Vertic Tropaquept, Aeric Tropaquept, Typic Ustochrept, Vertic Ustochrept, Typic Ustropept, Typic Haplustept, Vertic Haplustept (Inceptisols), Typic Haplustalf, Typic Paleustalf, Ultic Paleustalf, Kandic Paleustalf, Rhodic Paleustalf, Typic Rhodustalf, Typic Ochraqualf, Aeric Ochraqualf (Alfisols), Typic Ustorthent, Lithic Ustorthent, Aeric Fluvaquent and Typic Ustipsamment (Entisols), Typic Chromustert, Chromic Haplustert and Typic Haplustert (Vetisols) and Lithic Haplustolls (Mollisols). It was observed that most of the fine textured soils belonged to Inceptisols, Vertisols and Mollisol and the coarse textured soils to Alfisols and Entisols subgroups.

- Soils belonging to Vertic Haplaquept, Typic Tropaquept, Aeric Tropaquept, Typic Ustochrept and Vertic Haplustept subgroups are clay in texture with dense sub-surface layers, clay content increases with depth, slightly acidic to alkaline in reaction, free from salt accumulation, low in organic carbon content, non-calcareous in nature except Typic Tropaquept and Typic Ustochrept which contains > 2% $CaCO_3$, with medium to high cation exchange capacity. Soils of these subgroups are low in water transmission characteristics. However, these soils exhibit high to very high (21.2 to 28.4 cmm^{-1}) profile water storage capacity. They are very prone to soil and water erosion. Very high erosion index is observed in Vertic Haplustept and Aeric Tropaquept, high in Typic Tropaquept and Typic Ustochrept and medium in Vertic Haplaquept.

- Soils of Aeric Haplaquept, Vertic Tropaquept, Vertic Ustochrept, Typic Ustropept and Typic Haplustept subgroups are clay loam to sandy clay loam in texture, clay content increases with depth, dense sub-surface layers, slightly acidic to neutral in reaction, free from salt accumulation, low in organic carbon content, non-calcareous in nature with low to medium cation exchange capacity. These soils are low to moderate in water transmission characteristics. Profile water storage capacity of these subgroups varies from low to very high (8.1 to 24.0 cmm^{-1}). Soils of these subgroups are very prone to erosion and shows very high erosion index.

- Soils of eight subgroups under Alfisols 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 Ochraqualf, which contains > 2 % $CaCO_3$ in sub-surface layers. These are poor organic matter containing soils having low to medium cation exchange capacity. Soils of these subgroups exhibit moderate to high water transmission characteristic and medium to very high profile water storage capacity. Very high erosion index is observed in Aeric Ochraqualf, high in Typic Haplustalf, Kandic Paleustalf and Typic Ochraqualf, medium in Typic Paleustalf and Typic Rhodustalf. Low erosion index is observed in Ultic Paleustalf and Rhodic Paleustalf.

- Soils belonging to Typic Ustorthent, Lithic Ustorthent, Aeric Fluvaquent and Typic Ustipsamment subgroups are sandy loam to clay loam in texture with dense sub-surface layer, clay content increases with depth, moderately to slightly acidic in reaction. These soils are free from salt accumulation except Aeric Fluvaquent, which shows 1.55 to 2.85 dS/m EC_2, more salts are accumulated in sub-surface layers. Except Lithic Ustorthent other soils are non- calcareous in nature, Lithic Ustorthent contains > 2% $CaCO_3$. Soils of these subgroups are low to very low in water transmission characteristics with low to very high profile water storage capacity. All these soils are very prone to soil and water erosion and show very high erosion index, which varies from 25.95 to 36.79.

- Soils of Typic Chromustert, Chromic Haplustert and Typic Haplustert subgroups are clay in texture with tremendous swell-shrink potential and high bulk density. These soils are neutral to slightly alkaline in reaction with moderate concentration of soluble salts deposition. They are poor in organic matter, calcareous in nature, with very high cation exchange capacity. These soils show high to very high profile water storage capacity. Soils of these subgroups exihibit medium to very high erosion index.

- 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. Such soils are characterized by moderate cation exchange capacity. These soils show good permeability and transmission characteristics with very high profile water storage capacity. Soils show very high dispersion and erosion index.

- Profile water storage capacity of dominating soil groups of eastern region was determined. Out of 26 soil subgroups, 9 had very high, 7 had high to very high, 3 had high, 3 had medium to high, 2 had medium and 1 each had low to medium and low water storage capacity. The highest profile water storage capacity of 27.8 to 28.4 cm m^{-1} depth was found in Typic Ustochrept and the lowest of 8.9 to 9.8 cm m^{-1} depth was found in Typic Ustipsamment. Out of 10 soil subgroups in Inceptisols, 1 had low to medium, 1 had medium to high, 1 had high, 2 had high to very high and 5 had very high water storage capacity. Out of 8 soil subgroups in Alfisols, 1 had very high, 2 had high to very high, 1 had high, 2 had medium to high and 2 had medium water storage capacity. In Entisols very high profile water storage capacity was observed in Lithic Ustorthent and Aeric Fluvaquent, Varying from 20.5 to 26.9cm/m depth. The storage capacity was high to very high in Typic Ustorthent and low in Typic Ustipsamment. In Vertisols, very high profile water storage capacity was observed in Typic Haplustert and high to very high in Typic Chromustert and high in Chromic Haplustert. In Mollisols the profile water storage capacity was high to very high, varying from 16.1 to 27.8 cm m^{-1} depth. Moisture retention at field capacity, wilting point and available water in these soils was influenced by two sets of factors, one set influencing positively while the other negatively. While silt, clay, organic carbon, calcium carbonate and cation exchange capacity influenced water storage positively, sand and bulk density had negative influence. Regression analysis was done to develop equations for predicting water retention at field capacity and wilting point using soil parameters, viz. sand, silt, clay, bulk density, electrical conductivity, organic carbon, calcium carbonate and cation exchange capacity. Better prediction of available water was made through prediction of field capacity and wilting point instead of direct prediction of available water in soils.

- Soil erosion has been identified as a potential threat to sustainability of the Agricultural system of the eastern region.
- Soils of Aeric Haplaquept, Vertic Tropaquept Aeric Tropaquept, Vertic Usto chrept, Typic Haplustept of Inceptisol order, Aeric Ochraqualf of Afisol order, Typic Ustorthent, Lithic Ustorthent, Aeric Fluvaquent and Typic Ustipsamment of Entisol order, Chromic Haplustert and Typic Hapustert of Vertisol order and Lithic Haplustoll of Mollisol order were observed to be highly prone to erosion and dispersion. They warrant immediate attention for management in terms of efficient soil-water conservation.
- Erosion index (EI) was determined for surface as well as subsurface layers of twenty-six soil subgroups of eastern India. The erodibility was related to various physicochemical properties of the soils. In 0-15 cm layers, the highest erosion index of 45.86 was observed in Typic Ustipsamment followed by Vertic Ustochrept (41.62), Aeric Haplaquept (39.16) and the lowest EI (2.99) was observed in Rhodic Paleustalf. In 15-30 cm soil depth it varied from 36.89 in Aeric Fluvaquent to 7.26 in Typic Paleustalf. In the 30-150 cm layer, it varied from 40.85 in Aeric Fluvaquent to 8.29 in Ultic Paleustalf. Significantly higher value of EI was observed for 0-15 cm soil depth and no significant difference in EI was observed between 15-30 and 30-150 cm soil layers. In general, as the soil depth increases the erosion index decreases. A highly significant and negative relationship of erosion index with clay, silt + clay, maximum water holding capacity and highly significant, and positive relationship with sand and

dispersion ratio were observed. As the dispersion ratio increased, erosion index also increased indicating susceptibility of these soils to water erosion. Study suggested that all dominating subgroups of eastern region soils need some kind of soil and water conservation measures.

- Water transmission properties of the soils under unsaturated condition, *viz.* D (θ) and K (θ), were evaluated in specially designed plexiglass columns. Scaled soil water diffusivity, $D^*(\Theta)$ and pressure head, $h^*(\Theta)$ *versus* reduced soil water content, (Θ) were developed to estimate D (θ) and h (θ) values. The final equations are as follows:

  $D_i(\theta) = 1.565 \times 10^{-2} m_i^2 \exp(6.032\,\Theta)$

  $K_i(\theta) = 4.219 \times 10^{-1} mi^4 \exp(4.885\,\Theta)$

  $h_i(\theta) = 2.197 \times 10\text{-}7\, m_i^2 (\Theta)^{-4.611}$

  where $D_i(\theta)$ is given in m^2s^{-1}, $K_i(\theta)$ is given in ms^{-1} and 'h_i' is given in m, m_i is slope of the x (wetting front) versus $t^{1/2}$ plot for soil i . Thus, to estimate soil water diffusivity and pressure head of any soil 'i', a horizontal infiltration run has to be made to determine its 'm_i'.

- The scaling technique can be suitably used for evaluating hydraulic functions under field situations, by resorting to sampling from each soil horizon and packing the soil to bulk densities as close as possible to the field condition.

- The ψ-θ relationships, hydraulic conductivity, diffusivity and specific water capacity with soil water content suggest that frequent irrigations using small amount of water each time will be required to improve use efficiency of water applied to Alfisol and Entisol subgroups. Drip or sprinkler irrigation methods may prove useful to improve use efficiency of applied water and increase crop yield in these subgroups. Flood or furrow irrigation at long intervals, however, may be practiced in Inceptisol, Vertisol and Mollisol subgroups.

- Application of organics like FYM @ 10t/ha and practice of green manuring with Sesbania green manuring @ 40 kg seed/ha has been observed to be very effective for improving water-holding capacity of light-textured soils. This technique helps in enhancing moisture recharging in the profile and carry-over enough moisture for subsequent *rabi* crops. Use of locally available mulching materials like rice straw, etc. for reducing evaporation loss of profile water from soils can improve water-use efficiency of in *rabi* / summer season. Advanced sowing of *kharif* crops and adoption of short to medium duration varieties of rice can ensure successful rabi cultivation on residual soil moisture without any irrigation. This practice can increase the cropping intensity of the region. Mulching and paira cropping are the othe feasible alternatives for enhancing cropping intensity.

- In heavy textured soils, incorporation of paddy husk and powdered groundnut shells will improve water transmission properties and tehreby enhance water use efficiency of crops. Kaolinite dominated light textured acid soils have very high saturated hydraulic conductivity leading to heavy percolation losses of water. This problem can be considerably reduced by compaction. Compaction has been found to improve water holding capacity of lateritic soils.

1. Introduction

Area situated between latitudes of 17^0 N and 29^0 N and longitudes of 80^0 E and 97^0 E constitute the eastern region of India. The region includes eastern Uttar Pradesh (85,844 sq km), undivided Bihar & Jharkhand (1,73,877 sq km), Assam (78,438 sq km), Chhattisgarh (1,44,422 sq km), Orissa (-1,55,707 sq km) and West Bengal (88,751 sq km) states. Total geographical area of the eastern region is 73.60 M ha, which is 22% of the total geographical area of the country. Out of the 73.60 M ha geographical area of the eastern region, only about 45% (33.60 M ha) is the net cultivated area as against 46% (141 M ha) cultivated area of the country. The region is inhabited by about 34 per cent of total population and contributes to the food grain production of 58 million tones (34.6 per cent of the total). Though the region is rich in all natural resources, but the productivity of agricultural crop is not up to satisfactory level. Rice is dominant crop in the region but it is largely grown during kharif season. Other major field crops of the region are wheat, maize, finger millets, pulses, oil seeds and sugarcane. Productivity of these crops in this region is low as compared to national average yield. Average cropping intensity in eastern India is about 143%. Climate of the region is tropical, hot and sub-humid to humid with high rainfall. Average annual rainfall in this region varies from 1091 to 2477 mm with an average of 1526 mm, which is sufficient and substantial for growing any crop. Bulk of the rain (about 80%) occurs during the monsoon period. It has erratic temporal and spatial distribution with considerable year-to-year variation. Even in years when the total rainfall is adequate, long dry spells and inadequate rainfall at the crucial stages of the crop growth adversely contribute to instability in agricultural production. The plains of these regions invariably suffer from excess of the stagnating water causing waterlogging and crop damage during monsoon. On the contrary, the undulating topography and sloping lands suffers from excessive run-off and nutrient losses. The coastal areas are also vulnerable to seawater intrusion and cyclones.

Knowledge of physico-chemical and hydraulic characteristics of soil is essential for scheduling agricultural operations and preparation of any management strategy for water conservation, irrigation scheduling, drainage and solute migration, and development of various hydrological models (Singh *et al.* 1988; 1992; Singh and Bhargava 1994; Singh and Kundu 2005b). In canal irrigated areas of eastern India use efficiency of applied irrigation water is very low, often 30% or less (Pande and Reddy 1988; Singh *et al.* 2005). The region has good scope of irrigation expansion and rainwater conservation *in-situ*. 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 unirrigated areas for improving the prospect of yield enhancement and stabilization in this region. Formulation of sound management strategy to improve water use efficiency will require a clear understanding of soil water functional relationships, i.e. the capacity (content of water), intensity (force of water retention) and rate variables (rate of water movement through soil) of moisture availability in the soils and relationships among them. Study of dynamics of water in unsaturated soil systems requires knowledge of ψ-θ, K-θ, D-θ and C-θ relationships in the soils (where θ is volumetric water content in soil, ψ is suction with which water is retained by the soil, K is the rate at which water flows in the soil, D is soil water diffusivity, and C is the change in soil water content per unit change in suction). Information on this aspect is lacking for the soils of eastern region. Soil erosion has been identified as a potential threat to sustainability of the livelihood system of the people in eastern India (Singh *et al.* 2002; 2006). Adequate base line information on erodibility of different soil types of eastern India is not available for planning appropriate erosion control measures. Hence the present investigation was undertaken with the objectives (i) to study some physical and physico-chemical characteristics, (ii) to generate information on soil water retention characteristics, available water capacities and water transmission characteristics, (iii) to determine erosion indices for dominating soil subgroups of eastern India.

2. Different soil order and subgroups in eastern region

Soils of eastern region are mainly developed by the actions and interactions of relief, parent material and climate. Biotic features, mainly the natural vegetation follows the climatic patterns. Area covered under six soil orders in different states is presented in Table 1.Eastern region is dominated by Inceptisols by covering approximately 34 M ha area. In general, 22-75% area in different states are under Inceptisols. Soils of Eastern UP, West Bengal and Orissa states have more than 50% area under Inceptisols. Alfisols cover approximately 20 M ha area of eastern region. About 10-50% areas in different states are under Alfisols. In Chhattisgarh state, 6.9-_M ha (50%) area is under Alfisols. A considerable area (14.5 M ha) of this region is categorized under Entisols. More than 40% (3.76 M ha) area of Bihar state is covered by Entisols. In Eastern region, about 3 M ha area is under Vertisols, mainly in Chhattisgarh state. Hilly areas of Chhattisgarh and eastern UP have 0.09 and 0.07 M ha areas under Vertisols, respectively. In Assam state, 0.39 M ha area is categorized under Ultisols.

Table 1. Soils of the eastern region and their distribution

States	Soil orders											
	Entisols		Inceptisols		Alfisols		Vertisols		Mollisols		Ultisols	
	Area (M ha)	Percen tage	Area (M ha)	Percen tage	Area (M ha)	Percen tage	Area (M ha)	Percen tage	Area (M ha)	Percen tage	Area (M ha)	Percen tage
West Bengal	1.97	22.85	4.69	54.41	1.96	22.74	--		--		--	
Bihar	3.76	40.39	4.48	48.12	1.07	11.49	--		--		--	
Jharkhand	2.21	27.62	3.18	39.75	2.61	32.63	--		--		--	
Orissa	1.52	9.84	7.80	50.49	5.27	34.11	0.86	5.56	--		--	
Chhattisgarh	1.64	11.88	3.10	22.46	6.89	49.94	2.08	15.07	0.09	0.65	--	
Assam	1.81	30.42	2.96	49.75	0.79	13.27	--		--		0.39	6.56
Eastern U.P.	1.55	14.89	7.71	74.06	1.08	10.38	--		0.07	0.67	--	

Source: Haldar *et al.* (1992), Haldar *et al.* (1996), Sarkar *et al.* (1998), Sen *et al.* (1999), Singh *et al.* (2003), Tamgadge *et al.* (1999)

Soils of the country as a whole, are classified in eight soil orders (Table 2). However, only six soil orders are found in the eastern region. Aridisols and Oxisols are not formed under eastern region conditions Fig 1. In eastern region the dominating soil order is Inceptisols followed by Alfisols and Entisols. The lowest area covered by Mollisols (0.22%). Area under different subgroups in each soil order in respect of seven states of eastern region are presented in Table 3. Entisols are classified into Aeric Fluvaquents, Typic Ustipsamments, Typic Ustorthents, Lithic Ustorthents, Typic Haplaquents, Typic Udorthents, Typic Fluvaquents and Typic Ustifluvents –subgroups. Various subgroups under Inceptisols are Aeric Tropaquepts, Aeric Haplaquepts, Typic Ustochrepts, Vertic Haplaquepts, Vertic Tropaquepts, Typic Ustropepts, Typic Tropaquepts, Vertic Ustochrepts, Fluventic Ustochrepts, Typic Haplaquepts, Dystric Eutrochrepts, Typic Dystrochrepts, Umbric Dystrochrepts, Typic Haplustepts and Vertic Haplustepts; Alfisols are classified into Ultic Paleustalfs, Typic Paleustalfs, Rhodic Paleustalfs, Typic Rhodustalfs, Typic Ochraqualfs, Aeric Ochraqualfs, Typic Haplustalfs, Kandic Paleustalfs, Typic Hapludalfs, Mollic Hapludalfs and Vertic Ochraqualfs subgroups. Soils under Vertisols are classified as Typic Chromusterts, Chromic Haplusterts and Typic Haplusterts; under Mollisols as Lithic Haplustolls and Udic Haplustolls; and under Ultisols as Typic Hapludults and Typic Kandihumults.

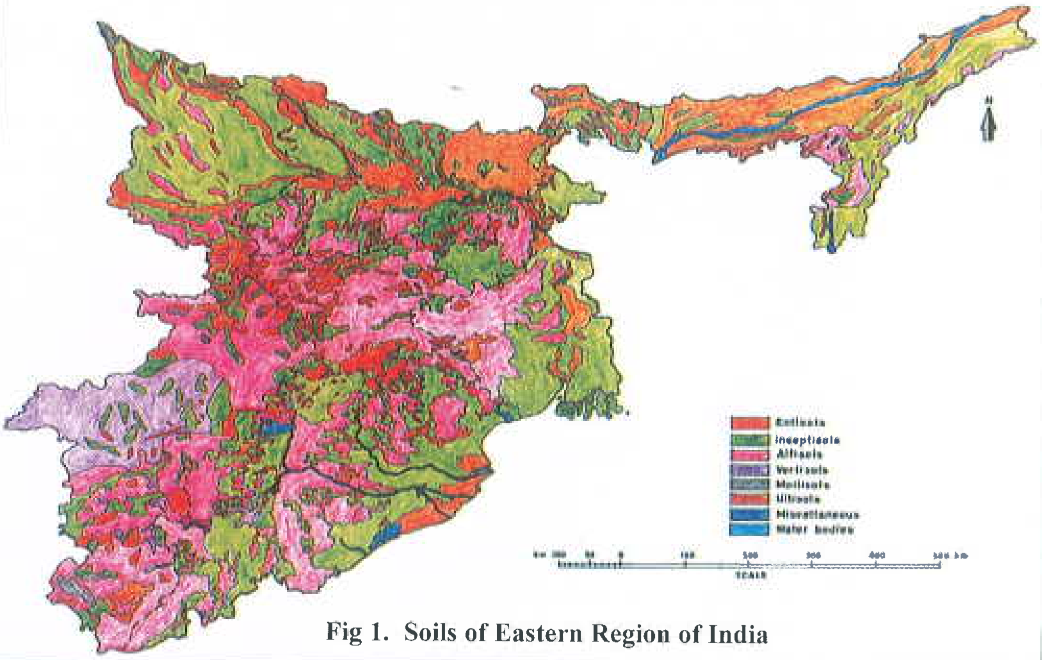


Fig 1. Soils of Eastern Region of India

Table 2. Distribution of different soil orders in India and in the eastern region

Soil orders	Area in India (Mha)	Area in Eastern India (Mha)	Area as a percentage of	
			India	Eastern region
Entisols	80.1	14.46	18.05	19.65
Inceptisols	95.8	33.92	35.41	46.09
Vertisols	26.3	2.94	11.18	3.99
Aridisols	14.6	--	--	--
Mollisols	8.0	0.16	2.00	0.22
Ultisols	0.8	0.39	48.75	0.53
Alfisols	79.7	19.67	24.68	26.73
Oxisols	0.3	--	--	--
Non classified	23.1	2.06	08.92	2.06
Total	328.7	73.60	22.39	100

Source: Velayutham and Bhattacharyya (2000)

Table 3. Land area under different soil subgroups in the states of eastern region

Soil orders	Subgroups	Area in 000 ha						
		West Bengal	Bihar	Jhar-khand	Orissa	Chhattis-garh	Assam	Eastern UP
Inceptisols	Aeric Tropaquepts				630.0			
	Aeric Haplaquepts	1574.8	598.6	821.6	3233.7		442.5	144.2
	Typic Ustochrepts	794.6	1920.8	2307.4	1594.8			6121.3
	Vertic Haplaquepts	463.7	159.2					
	Vertic Tropaquepts				486.2			
	Typic Ustropepts				556.3			
	Typic Tropaquepts				401.3			
	Vertic Ustochrepts		863.5	51.6	230.6			391.6
	Fluventic Ustochrepts	326.7						722.4
	Typic Haplaquepts	1271.2	941.5		665.4		455.9	324.6
	Dystric Eutrochrepts						511.6	
	Typic Dystrochrepts	206.1					1104.8	
	Umbric Dystrochrepts	48.2					441.4	
	Typic Haplustepts					1984.2		
	Vertic Haplustepts					1115.2		

Soil orders	Subgroups	Area in 000 ha						
		West Bengal	Bihar	Jhar-khand	Orissa	Chhattis-garh	Assam	Eastern UP
Alfisols	Ultic Paleustalfs	207.2			642.5			
	Typic Paleustalfs	68.1		300.8	134.5			77.9
	Rhodic Paleustalfs	107.5			329.6			
	Typic Rhodustalfs	3.4		295.7	1672.5	1549.4		40.8
	Typic Ochraqualfs	123.8	316.6	72.5	10.0			113.4
	Aeric Ochraqualfs	151.4	337.3	413.4	627.8			
	Typic Haplustalfs	964.1	125.6	1521.9	1664.5	5340.4		843.1
	Kandic Paleustalfs				184.9			
	Typic Hapludalfs	16.6					512.2	
	Mollic Hapludalfs						278.7	
	Vertic Ochraqualfs	317.4	293.3					
Entisol	Aeric Fluvaquents		377.1		301.2		712.2	165.7
	Typic Ustipsamments	69.7	763.3		137.9			609.9
	Typic Ustorthents	77.5		553.4	928.2	364.64		24.7
	Lithic Ustorthents	337.2		1659.7	153.0	1276.9		258.6
	Typic Haplaquents	204.8	165.2				426.1	
	Typic Udorthents	107.7	593.1					
	Typic Fluvaquents	341.6					666.7	
	Typic Ustifluvents	833.8	1860.7					493.5
Vertisols	Typic Chromusterts				330			
	Chromic Haplusterts					1468.5		
	Typic Haplusterts				530	611.52		
Mollisols	Lithic Haplustolls					89.60		
	Udic Haplustolls							68.3
Ultisols	Typic Hapludults						171.6	
	Typic Kandihumults						219.6	

Source: Haldar et al. (1992), Haldar et al. (1996), Tamgadge et al. (1999), Sarkar et al. (1998), Sen et al. (1999), Singh et al. (2003),

3. Profile soil sampling from dominant soil subgroups of the eastern region

Soil samples of 26 dominant subgroups belonging to 5 soil orders, viz. Entisols, Inceptisols, Alfisols, Vertisols and Mollisols were used in the present study. The details of locations and the subgroups are presented in Table 4. Three soil profiles were dug for each soil sub-group at each site and soil samples collected from 0-30, 30-60 and 60-90 cm depth of each profile were sampled for analysis of important physical and physico-chemical characteristics. For estimation of erosion indices, soil samples were collected from 0 – 15, 15 – 30 and 30 –150 cm depth.

Table 4. Location and classification of soils of eastern India used in the study

Soil Order	Soil subgroup	Genetic soil nomenclature	Location		
			Village	District	State
Inceptisol	Vertic Haplaquept	Old deltaic alluvial soil	Kamakhyanagar	Dhenkanal	Orissa
	Aeric Haplaquept	Deltaic alluvial soil	Chapra	Nadia	West Bengal
	Typic Tropaquept	Deltaic alluvial soil	Basta	Balasore	Orissa
	Vertic Tropaquept	Deltaic alluvial soil	Begunia	Khurda	Orissa
	Aeric Tropaquept	Deltaic alluvial soil	Bhubaneswar	Khurda	Orissa
	Typic Ustochrept	Deltaic alluvial soil	Hatiya	Ranchi	Jharkhand
	Vertic Ustocrept	Old deltaic alluvial soil	Dhenkanal	Dhenkanal	Orissa
	Typic Ustropept	Deltaic alluvial soil	Polosara	Ganjam	Orissa
	Typic Haplustept	Deltaic alluvial soil	Bilaspur	Bilaspur	Chhattisgarh
	Vertic Haplustept	Old deltaic alluvial soil	Raipur	Raipur	Chhattisgarh
Alfisol	Typic Haplustalf	Lateritic soil	Jamankira	Sambalpur	Orissa
	Typic Paleustalf	Lateritic soil	Bero	Ranchi	Jharkhand
	Ultic Paleustalf	Lateritic soil	Kharagpur	Medinipur	West Bengal
	Kandic Paleustalf	Lateritic soil	Semiliguda	Koraput	Orissa
	Rhodic Paleustalf	Lateritic soil	Karra	Gumla	Jharkhand
	Typic Rhodustalf	Red and lateritic soil	Tomar	Ranchi	Jharkhand
	Typic Ochraqualf	Lateritic soil	Kendujhargarh	Kendujhar	Orissa
	Aeric Ochraqualf	Lateritic soil	Murda	Mayurbhanj	Orissa
	Typic Ustorthent	Deltaic alluvial soil	Anandpur	Kendhujhar	Orissa
	Lithic Ustorthent	Lateritic soil	Kalamati	Ranchi	Jharkhand

Soil Order	Soil subgroup	Genetic soil nomenclature	Location		
			Village	District	State
	Aeric Fluvaquent	Coastal salt affected soil	Erasma	Jagatsinghpur	Orissa
	Typic Ustipsamment	Deltaic alluvial soil	Chatrapur	Ganjam	Orissa
Vertisol	Typic Chromustert	Black soil	Bhawanipatana	Kalahandi	Orissa
	Chromic Haplustert	Black soil	Janjgir	Janjgir	Chhattisgarh
	Typic Haplustert	Black soil	Bilaspur	Bilaspur	Chhattisgarh
Mollisol	Lithic Haplustoll	Tarai soil	Jashpur	Jashpur	Chhattisgarh

4. Determination of physico-chemical and hydraulic characteristics of the soils

Important physical and chemical characteristics of the soils were determined by following standard procedures. Mechanical composition the soil samples were determined following international pipette method and bulk density in undisturbed samples collected with metal cores of 4.2 cm diameter and 5.8 cm height (Klute 1986). Organic carbon, calcium carbonate and cation exchange capacity were determined by standard analytical methods (Jackson 1976). For determination of water retention, undisturbed soil samples were collected using metal cores of 5-cm diameter from all these depths. Water retention at different tensions was estimated by using pressure plate apparatus (Richards 1965). Water retention at 10 kPa tension 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 was classified according to moisture storage rating given by Rao and Prasadini (1998).

Horizontal infiltration experiments were carried out in plexiglass columns of 0.35 m length and 0.036 m diameter. The columns were prepared by joining plexiglass segments placed one over another in opposite direction keeping the eccentric holes in them upright and fitted with a coarse sintered glass plate at one end. They were filled as uniformly as possible with soil samples at bulk density of 1.5 Mg m^{-3}. For achieving the desired bulk density, weighed soil was filled in each segment of the columns one by one on a vibrator. Columns were placed horizontally on a wooden stand and water was introduced at the inlet end from Marriottee tube at a constant suction of 0.2 kPa of water. Water entering the column was measured volumetrically and distance from water source to the wetting front was visually observed. After completion of infiltration, the column was sectioned into 1 cm segments and water content in the soil segments determined gravimetrically. The infiltration tests were replicated thrice with each soil.

Soil water diffusivity functions, $D(\theta)$ were calculated from experimental water content profiles using relationship given by Bruce and Klute (1956):

$$D(\theta) = -1/2t \cdot dx/d\theta \int_{\theta i}^{\theta s} x\, d\theta \quad \ldots\ldots\ldots\ldots \quad (1)$$

where $D(\theta)$ is soil water diffusivity at the volumetric water content θ, θi is initial water content, θs is water content at saturation, x is distance from the water source and 't' is the duration of water entry into the column.

Unsaturated hydraulic conductivity, $K(\theta)$ was worked out from the following relationship:

$$K(\theta) = D(\theta)\, d\theta/dh \quad \ldots\ldots\ldots\ldots \quad (2)$$

where h is soil water suction and $d\theta/dh$ is slope of the soil water retention curves obtained by using pressure plate apparatus.

Weighted mean diffusivity of water in soil, ($\overline{D}$) was worked out from the following equation given by Gardner *et al.* (1959):

$$\overline{D} = 5/3\, [\, 1/(\theta s - \theta i)\,]^{5/3} \int_{\theta i}^{\theta s} D(\theta) \cdot (\theta - \theta i)^{2/3}\, d\theta \quad \ldots\ldots\ldots\ldots \quad (3)$$

Intrinsic weighted mean diffusivity ($\overline{D}i$) was calculated from the weighted mean diffusivity by using following relationship:

$$\overline{D}i = \eta/(\gamma \cos H) \cdot \overline{D} \quad \ldots\ldots\ldots\ldots \quad (4)$$

where η is viscosity, γ is surface tension, and H is the angle of contact between water and soil.

Penetrability (P), intrinsic penetrability (Pi) and sorptivity (S) were calculated by using following relationships:

$P = x/t^{1/2}$ .... (5)

$P = Pi\ (\gamma/\eta \cos H)^{1/2}$ .... (6)

$S = I/t^{1/2}$ .... (7)

where x is distance of wetting front and I is cumulative infiltration.

Scaled soil water diffusivity $D^*(\Theta)$, hydraulic conductivity $K^*(\Theta)$ and pressure head $h^*(\Theta)$ were obtained from the following equations (Reichardt *et al.* 1972):

$D^*(\Theta) = \eta\ D_i(\theta)/\gamma\lambda$ .... (8)

$K^*(\Theta) = \eta\ K_i(\theta)/\lambda i^2 \rho g$ .... (9)

$h^*(\Theta) = \lambda i\ \rho g\ hi(\theta)/\gamma$ .... (10)

where the symbols with astericks represents respective scaled variables or parameters, g is acceleration due to gravity, ρ is the density of water, (Θ) is dimensionless soil water content defined as:

$(\Theta) = (\theta - \theta i)/(\theta s - \theta i)$ .... (11)

where θi is initial soil water content and ès is water content in soil at saturation.

Microscopic characteristic length λ_i of soils could determined relative to a reference soil to which an arbitrary value of $\lambda = \lambda_s$ is assigned using the relation

$\lambda_i = \lambda_s\ (m_i/m_s)^2$ .... (12)

where m_i is slope of the x versus $t^{1/2}$ plot for soil i, and m_s is the slope of x versus $t^{1/2}$ plot for the reference soil.

Erosion indices i.e. dispersion ratio and erosion index were determined as described by Middleton (1930) and Sahi et al. (1977), respectively.

Dispersion ratio = 100 (silt + clay dispersible in water)/ (total silt + clay) ..... (13)

Dispersible silt + clay was determined by dispersing 25 g soil in 1000 ml distilled water taken in 1000 ml cylinder, without adding any dispersing agent, and by shaking cylinder from end to end for 20 times and pepetting out 25 ml of soil suspension from 10 cm depth (international pipette method: Piper 1966).

Erosion index was computed from the following relationship:

Erosion index = Dispersion ratio/(clay/0.5 water holding capacity) …… (14)

4.1 Physico-chemical characteristics:

Important physical characteristics of the soils are presented in Table 5. The texture of the studied subgroups varied from sandy loam to clay. Clay content varied from 12.4 % in Typic Ustipsamment to 62.8 % in Typic Ustochrept, silt content varied from 4.9 % again in Typic Ustipsamment to 47.1% in Typic Tropaquept and sand fraction varied from 7.3 % in Typic Tropaquept to 82.7% in Typic Ustipsamment. Out of 26 soil subgroups, 9 were clay in texture, 6 sandy clay loam, 3 sandy clay, 7 clay loam and 1 sandy loam. Most of the fine textured soils were found in Inceptisol, Vertisol, Mollisol, and the coarse textured soils in Alfisols and Entisols. Bulk density of the soils varied from 1.33 to 1.61 Mg m^{-3}; highest bulk density was observed in Chromic Haplustert varying from 1.52 to 1.61 Mg m^{-3}, followed by Vertic Haplustept, Typic Haplustept and Ultic Paleustalf, varying from 1.37 to 1.58 Mg m^{-3} and the lowest 1.33 to 1.44 Mg m^{-3} was observed in Lithic Haplustoll.

Table 5. Salient physical characteristics of dominant soil subgroups of eastern India

Name of the soil subgroups	Soil depth (cm)	Particle Size (%)			Textural class	Bulk density (Mg m^{-3})
		Sand	Silt	Clay		
Vertic Haplaquept	0-30	18.6	32.7	48.7	c	1.40
	30-60	16.2	31.4	52.4	c	1.41
	60-90	16.4	28.4	55.2	c	1.42
Aeric Haplaquept	0-30	61.1	15.3	23.7	scl	1.46
	30-60	48.1	15.7	36.2	sc	1.48
	60-90	49.6	14.9	35.5	sc	1.48
Typic Tropaquept	0-30	9.4	47.1	43.5	c	1.39
	30-60	7.4	42.6	50.0	c	1.40
	60-90	7.3	39.9	52.8	c	1.40
Vertic Tropaquept	0-30	64.2	15.6	20.3	scl	1.49
	30-60	60.2	15.7	24.1	scl	1.50
	60-90	57.0	18.0	25.0	scl	1.52

Name of the soil subgroups	Soil depth (cm)	Particle Size (%)			Textural class	Bulk density (Mg m^{-3})
		Sand	Silt	Clay		
Aeric Tropaquept	0-30	12.7	43.9	43.5	c	1.43
	30-60	9.6	43.7	46.7	c	1.44
	60-90	9.1	42.4	48.5	c	1.45
Typic Ustochrept	0-30	15.9	31.9	51.3	c	1.39
	30-60	14.5	26.8	58.7	c	1.40
	60-90	8.3	28.9	62.8	c	1.41
Vertic Ustochrept	0-30	64.4	13.6	22.1	scl	1.49
	30-60	54.2	13.2	32.6	scl	1.48
	60-90	53.0	13.0	34.0	scl	1.48
Typic Ustropept	0-30	47.4	21.6	31.1	scl	1.44
	30-60	39.8	22.7	37.5	cl	1.45
	60-90	32.8	26.8	40.4	c	1.46
Typic Haplustept	0-30	48.9	16.6	34.5	sc	1.37
	30-60	43.7	20.6	35.7	cl	1.50
	60-90	37.9	20.9	41.2	c	1.58
Vertic Haplustept	0-30	30.5	18.8	50.7	c	1.39
	30-60	29.3	16.5	54.2	c	1.53
	60-90	29.2	16.3	54.5	c	1.53
Typic Haplustalf	0-30	35.9	30.7	33.4	cl	1.43
	30-60	43.6	26.1	30.3	cl	1.44
	60-90	41.5	25.3	33.2	cl	1.45
Typic Paleustalf	0-30	44.2	13.8	42.1	c	1.47
	30-60	40.5	14.2	45.3	c	1.49
	60-90	34.3	15.1	50.6	c	1.51
Ultic Paleustalf	0-30	67.7	10.3	22.1	scl	1.52
	30-60	60.6	10.9	28.5	scl	1.49
	60-90	59.0	10.1	30.9	scl	1.55
Kandic Paleustalf	0-30	55.1	14.9	30.1	scl	1.46
	30-60	43.9	14.8	41.3	c	1.48
	60-90	42.7	17.3	40.0	c	1.49
Rhodic Paleustalf	0-30	42.8	15.1	42.2	c	1.40
	30-60	47.5	14.9	37.6	sc	1.42
	60-90	47.8	14.9	37.3	sc	1.43
Typic Rhodustalf	0-30	56.4	15.3	28.4	scl	1.49
	30-60	44.5	16.9	38.6	sc	1.52
	60-90	45.3	14.9	39.8	sc	1.53
Typic Ochraqualf	0-30	32.8	27.8	39.5	cl	1.41
	30-60	33.4	22.0	44.6	c	1.43
	60-90	34.3	22.6	43.1	c	1.44
Aeric Ochraqualf	0-30	41.2	31.1	27.7	cl	1.43
	30-60	33.4	36.4	30.2	cl	1.45
	60-90	29.8	36.0	34.2	cl	1.47

Name of the soil subgroups	Soil depth (cm)	Particle Size (%)			Textural class	Bulk density (Mg m^{-3})
		Sand	Silt	Clay		
Typic Ustorthent	0-30	45.3	28.5	26.2	l	1.45
	30-60	41.5	25.9	32.6	cl	1.46
	60-90	34.5	29.7	35.8	cl	1.48
Lithic Ustorthent	0-30	40.0	25.1	34.9	cl	1.45
	30-60	39.0	22.8	38.2	cl	1.46
Aeric Fluvaquent	0-30	34.3	27.0	38.7	cl	1.43
	30-60	27.2	27.0	45.8	c	1.44
	60-90	26.0	26.0	48.0	c	1.43
Typic Ustipsamment	0-30	82.7	4.9	12.4	sl	1.53
	30-60	74.5	5.8	19.7	sl	1.54
	60-90	73.1	7.0	19.9	sl	1.55
Typic Chromustert	0-30	32.0	25.1	43.0	c	1.37
	30-60	30.9	23.2	45.9	c	1.39
	60-90	27.0	25.5	47.5	c	1.40
Chromic Haplustert	0-30	29.7	24.3	46.0	c	1.52
	30-60	25.9	24.6	49.5	c	1.57
	60-90	28.7	22.4	48.9	c	1.61
Typic Haplustert	0-30	32.4	19.9	47.7	c	1.39
	30-60	31.9	22.9	45.2	c	1.46
	60-90	30.9	24.1	45.0	c	1.52
Lithic Haplustoll	0-30	54.1	14.9	31.0	scl	1.33
	30-60	42.6	18.9	38.5	cl	1.42
	60-90	39.4	20.9	39.7	cl	1.44

Important chemical characteristics of the soils are presented in Table 6. Data on salt content in terms of electrical conductivity revealed that all studied soil subgroups were free from salinity problem except Aeric Fluvaquent subgroup, where EC_2 varied from 1.55 to 2.85 dSm^{-1}, indicating moderate level of salinity in this subgroup. In other subgroups EC_2 varied from 0.01 to 0.63 dSm^{-1}. pH of the soil varied from 5.7 to 8.3. Out of 26 soil subgroups, 18 subgroups had pH between 6 and7, 7 had pH between 7 and 8.3 and 1 sub-group had pH less than 6. Except Vertisols most of the subgroups of Inceptisol, Alfisol, Entisol and Mollisol were acidic in nature. All the soil subgroups were generally low in organic carbon content and it varied from 0.06 to 0.97%. The highest organic carbon content was observed in Lithic Haplustoll (0.65 – 0.97%) followed by Vertic Haplustept and Typic Ustochrept (0.23 to 0.61 %) and the lowest in Vertic Ustochrept (0.06 to 0.32%). All the soil subgroups were non-calcareous in nature as $CaCO_3$ varied from 0.2 to 3.9 %. Cation exchange capacity varied widely (5.3 to 48.7 cmol (p$^+$) kg^{-1}) depending upon texture of the soil. Higher the clay content, higher was the CEC of the soils. The highest CEC was observed in Vertic Haplaquept (42.2 - 48.7 cmol (p$^+$) kg^{-1}) followed by Typic Ustochrept (35.7 – 46.3 me/100g) and the lowest (8.4 – 9.0 cmol (p$^+$) kg^{-1}) in Vertic Tropaquept.

Table 6. Salient chemical characteristics of dominant soil subgroups of eastern India

Name of the soil subgroup	Soil depth (cm)	EC$_2$ (dS/m)	pH$_2$	OC (%)	CaCO$_3$ (%)	CEC [cmol (p$^+$) kg^{-1}]
Vertic Haplaquept	0-30	0.20	6.4	0.54	0.7	42.2
	30-60	0.32	6.6	0.40	1.4	46.1
	60-90	0.24	6.8	0.33	1.4	48.7
Aeric Haplaquept	0-30	0.10	6.0	0.44	0.5	13.1
	30-60	0.09	6.1	0.23	0.6	16.0
	60-90	0.09	6.4	0.13	0.8	21.9
Typic Tropaquept	0-30	0.08	6.4	0.42	2.2	17.4
	30-60	0.07	6.2	0.27	2.2	20.8
	60-90	0.10	6.3	0.30	2.2	22.6
Vertic Tropaquept	0-30	0.21	6.6	0.32	0.8	9.0
	30-60	0.16	6.9	0.19	0.8	8.4
	60-90	0.19	6.9	0.19	0.4	8.7
Aeric Tropaquept	0-30	0.20	6.4	0.22	0.7	25.5
	30-60	0.17	6.8	0.09	0.8	27.2
	60-90	0.35	7.6	0.18	1.0	26.5
Typic Ustochrept	0-30	0.20	7.2	0.61	1.9	35.7
	30-60	0.63	7.4	0.26	2.2	43.1
	60-90	0.34	7.7	0.23	2.2	46.3
Vertic Ustochrept	0-30	0.15	5.9	0.32	0.4	9.5
	30-60	0.26	6.9	0.09	0.6	13.1
	60-90	0.43	7.1	0.06	0.9	13.9
Typic Ustropept	0-30	0.16	6.8	0.49	0.9	15.3
	30-60	0.12	6.9	0.21	0.6	23.9
	60-90	0.20	6.9	0.28	0.5	27.0
Typic Haplustept	0-30	0.06	6.7	0.57	0.9	15.4
	30-60	0.02	7.3	0.28	0.7	13.5
	60-90	0.02	7.4	0.34	0.7	17.25
Vertic Haplustept	0-30	0.08	7.2	0.72	0.5	21.45
	30-60	0.06	7.9	0.21	0.4	24.20
	60-90	0.07	8.0	0.23	0.6	24.20
Typic Haplustalf	0-30	0.06	6.0	0.52	1.1	16.2
	30-60	0.03	6.3	0.29	0.9	14.4
	60-90	0.04	6.6	0.29	1.2	15.2

Name of the soil subgroup	Soil depth (cm)	EC_2 (dS/m)	pH_2	OC (%)	$CaCO_3$ (%)	CEC [cmol (p^+) kg^{-1}]
Typic Paleustalf	0-30	0.08	6.0	0.36	0.4	9.7
	30-60	0.09	5.9	0.31	0.6	10.1
	60-90	0.07	6.2	0.26	0.6	13.2
Ultic Paleustalf	0-30	0.07	5.8	0.32	0.4	7.6
	30-60	0.07	5.7	0.18	0.5	10.0
	60-90	0.07	6.0	0.18	0.7	12.2
Kandic Paleustalf	0-30	0.05	6.3	0.28	1.5	11.1
	30-60	0.03	6.2	0.41	1.7	17.0
	60-90	0.03	6.1	0.44	1.4	14.4
Rhodic Paleustalf	0-30	0.09	6.9	0.45	0.9	12.3
	30-60	0.07	6.8	0.35	1.2	27.5
	60-90	0.07	6.7	0.23	1.3	24.0
Typic Rhodustalf	0-30	0.47	7.1	0.44	1.4	16.1
	30-60	0.28	7.3	0.34	1.0	20.2
	60-90	0.09	7.2	0.29	1.3	22.2
Typic Ochraqualf	0-30	0.10	6.1	0.38	1.8	20.4
	30-60	0.12	6.7	0.14	2.2	23.5
	60-90	0.12	7.0	0.14	2.0	22.6
Aeric Ochraqualf	0-30	0.03	5.4	0.37	1.6	15.5
	30-60	0.02	5.7	0.21	1.3	18.7
	60-90	0.02	6.0	0.20	1.1	18.7
Typic Ustorthent	0-30	0.05	5.6	0.39	0.8	12.7
	30-60	0.04	5.9	0.21	0.8	16.7
	60-90	0.04	6.0	0.15	0.8	16.4
Lithic Ustorthent	0-30	0.10	6.2	0.42	2.1	16.9
	30-60	0.13	6.9	0.21	2.6	19.8
Aeric Fluvaquent	0-30	1.55	6.1	0.48	1.2	24.2
	30-60	2.12	7.1	0.13	1.2	25.9
	60-90	2.85	7.5	0.16	1.4	31.9
Typic Ustipsamment	0-30	0.08	7.0	0.16	0.2	5.3
	30-60	0.07	6.7	0.16	0.3	9.8
	60-90	0.14	6.6	0.22	0.2	9.6

Name of the soil subgroup	**Soil depth (cm)**	**EC_2 (dS/m)**	**pH_2**	**OC (%)**	**$CaCO_3$ (%)**	**CEC [cmol (p^+) kg^{-1}]**
Typic Chromustert	0-30	0.22	7.1	0.51	1.8	26.5
	30-60	0.26	7.7	0.36	1.5	30.2
	60-90	0.35	7.9	0.30	2.2	29.6
Chromic Haplustert	0-30	0.07	7.3	0.20	1.6	19.9
	30-60	0.04	7.6	0.28	3.9	24.0
	60-90	0.06	7.7	0.27	1.4	23.7
Typic Haplustert	0-30	0.07	7.7	0.57	0.8	22.8
	30-60	0.05	8.3	0.34	0.4	20.3
	60-90	0.05	8.2	0.29	0.7	21.7
Lithic Haplustoll	0-30	0.01	6.0	0.79	0.8	14.2
	30-60	0.02	6.0	0.97	0.6	18.9
	60-90	0.02	6.1	0.65	0.8	19.9

4.2 Soil erodibility

Soil erosion is greatly influenced by erosivity and erodibility. While erosivity of soils depends on rainfall, soil erodibility broadly depends on soil properties, topoghaphic features of land, and management practices of land and crop. 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 from time to time to assess soil erodibility (Barnett and Rogers, 1966; Wischmeir *et al*.1971). Kaur *et al.* (2003) made a detailed review of researches on erodibility of Indian Soils. These equations are also very cumbersome, as they require determination of many parameters. Erosion index (EI) is a simple and reliable parameter (Sahi, *et al.* 1977 and Gupta, *et al*.1998) 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. Soil erosion has been identified as a potential threat to sustainability of the livelihood system of the people in eastern India. In the eastern region, Chhitisgahr is reported to have the largest land area (about 6.93 Mha) is affected by different degree of soil erosion followed by Orissa (5.37 Mha), Bihar and Jharkhand (4.05 Mha), eastern UP (3.13 Mha), West Bengal (1.71Mha) and Assam (1.38 Mha), respectively (Sarkar *et al.* (1998 ; 2000), Haldar *et al.* (1996), Singh *et al.* (2003), Tamgadge *et al.* (1999), Sen *et al.* (1999), Haldar *et al.* (1992). Information on erodibility of different soil types of eastern India is scanty. Erosion indices were determined for surface as well as subsurface layers of the soil profiles and soil erodibility were related to various physicochemical properties of the soils.

4.3 Dispersion ratio (DR)

Mean values of dispersion ratio (DR) for 0-15, 15-30 and 30-150 cm soil depth are presented in Table 7. In 0-15cm soil depth the highest dispersion ratio (DR) 87.7 was observed in Typic Haplustept followed by Typic Haplustert 73.8 and Vertic Haplustept 71.4 and lowest 7.3 was observed in Rhodic Paleustalf. No significant difference were observed between Aeric Tropaquept and Typic Ochraqualf, between Typic Ustropept Typic Haplustalf and Kandic Paleustalf and in Kandic Paleustalf and Typic Ustipsamment. The average mean value for this depth was observed 45.2 which was significantly different from 30-150 cm soil depth value however, no significant difference was observed between between 0 –15 and 15 –30 cm soil depth values. In 15-30 cm soil depth the highest DR 87.4 was observed in Aeric Fluvaquent followed by Typic Haplustept 86.6 and lowest 13.3 was observed in Ultic Paleustalf. No significant difference were observed between Aeric Tropaquept and Lithic Ustorthent, in Aeric Haplaquept Typic Tropaquept and Aeric Ochraqualf and between Vertic Haplaquept Typic Ochraqualf and Typic Ustorthent. Similarly no significant difference was observed between Typic Ustropept and Typic Ustorthent, in Rhodic Paleustalf and Kandic Paleustalf and in Typic Rhodustalf and Typic Haplustalf. The average value for this depth was 44.4 and significant difference was observed between the average values of 0-15 and 15-30 cm soil depths. In 30-150 cm soil depth the highest DR 91.6 was observed again in the same subgroup i.e. Aeric Fluvaquent followed by Typic Haplustept 82.2 and Typic Haplustert 76.8 and lowest 14.8 was observed in Ultic Paleustalf. No significant difference were observed between Aeric Haplaquept Typic Ustochrept and Vertic Tropaquept and in Typic Tropaquept and Typic Ustipsamment and in Typic Ustipsamment and Typic Ustorthent. Similarly no significant difference was observed between Typic Ustropept and Kandic Paleustalf, in Typic Ochraqualf Typic Haplustalf and Typic Chromustert and in Vertic Haplaquept and Typic Paleustalf. Significantly higher mean value 46.4 was observed for this depth. For all the soil groups and depth the highest DR value 85.5 was observed in Typic Haplustept followed by Aeric Fluvaquent (81.3), Typic Haplustert (74.9), Chromic Haplustert (70.6), Vertic Haplustept (66.8) and lowest 15.60 was observed in Ultic Paleustalf.

Dispersion ratio (DR) of < 5, 6-10, 11-15, 16-25, 26-30 and > 30 were categories as very stable, stable, fairly stable, somewhat unstable, unstable and very unstable. Out of 26 soil subgroups, 21 had very unstable category, 2 unstable and 3 comes under somewhat unstable category. Very unstable DR was observed in Vertic Haplaquept, Aeric Haplaquept, Typic Tropaquept, Vertic Tropaquept, Aeric Tropaquept, Typic Ustochrept, Vertic Ustochrept, Typic Ustropept, Typic Haplustept, Vertic Haplustept, Typic Haplustalf, Kandic Paleustalf, Typic Ochraqualf and Aeric Ochraqualf, Typic Ustorthent, Lithic Ustorthent, Aeric Fluvaquent, Typic Ustipsamment, Chromic Haplustert, Typic Haplustert and Lithic Haplustolls. Unstable Dr was observed in Typic Paleustalf and Typic Chromustert. Somewhat unstable DR was observed in Ultic Paleustalf, Rhodic Paleustalf and Typic Rhodustalf soil subgroups.

4.4 Erosion index (EI)

Mean values of erosion index (EI) for 0-15, 15-30 and 30-150 cm soil depth are presented in Table 8. In 0-15 cm soil depth the highest EI 45.86 was observed in Typic Ustipsamment followed by Vertic Haplustept (43.86), Vertic Ustochrept (41.62), Aeric Haplaquept (39.16), Vertic Tropaquept (36.81), Typic Haplustert (35.98), Lithic Ustorthent (35.48), Aeric Fluvaquent (32.63) and Typic Ustorthent (32.27) and lowest 2.99 in Rhodic Paleustalf. No significant difference was observed in Aeric Fluvaquent and Typic Ustorthent, in Aeric Tropaquept Typic Ochraqualf Typic Haplustalf and Kandic Paleustalf, in Typic Ustropept Typic Paleustalf and Aeric Ochraqualf and in Vertic Haplaquept Typic Tropaquept UlticPaleustalf and Typic Rhodustalf. In 15-30 cm soil depth the highest value of EI 42.54 was observed in Typic Haplustept followed by Aeric Fluvaquent (36.89), Vertic Ustochrept 35.08, Typic Ustipsamment 34.92,Vertic Tropaquept 30.97 and lowest 7.26 was observed in Typic Paleustalf. No significant difference was observed in Vertic Ustochrept and Typic Ustipsamment, in Aeric Tropaquept and Typic Ustochrept, in Typic Ustropept and Lithic Ustorthent, in Vertic Haplaquept and Typic Tropaquept, in Typic Rhodustalf and Kandic Paleustalf, in Typic Ochraqualf Aeric Ochraqualf and Typic Haplustalf and in Ultic Paleustalf and Typic Paleustalf. In 30-150 cm soil depth ER values varied from 8.29 in Ultic Paleustalf to 40.85 in Aeric Fluvaquent No significant difference was observed in Aeric Tropaquept and Lithic Ustorthent, in Aeric Ochraqualf and Typic Ustorthent, in Typic Ustochrept and Typic Haplustalf, in Vertic Haplaquept and Kandic Paleustalf, in Typic Ustropept Typic Tropaquept Typic Ochraqualf and Typic Chromustert, in Ultic Paleustalf Rhodic Paleustalf and Typic Rhodustalf. Mean values

Table 7. Dispersion ratio of dominating soil subgroups of eastern India

Soil subgroup	Dispersion ratio (DR)				
	Soil depth (cm)			Mean D R	Category
	0- 15	15 -30	30 –150		
Vertic Haplaquept	33.3	38.9	26.2	32.8	VU
Aeric Haplaquept	43.9	33.3	47.9	41.7	VU
Typic Tropaquept	32.7	33.0	40.8	35.5	VU
Vertic Tropaquept	51.9	42.9	48.7	47.8	VU
Aeric Tropaquept	45.9	45.3	56.5	49.2	VU
Typic Ustochrept	40.2	46.8	49.3	45.4	VU
Vertic Ustochrept	46.7	51.5	68.0	55.4	VU
Typic Ustropept	35.3	37.6	30.7	34.5	VU
Typic Haplustept	87.7	86.6	82.2	85.5	VU
Vertic Haplustept	71.4	64.2	64.9	66.8	VU
Typic Haplustalf	35.2	31.5	34.7	33.8	VU
Typic Paleustalf	38.8	22.7	26.4	29.3	U
Ultic Paleustalf	18.7	13.3	14.8	15.6	SU
Kandic Paleustalf	36.5	30.9	31.6	33.0	VU
Rhodic Paleustalf	7.3	30.4	22.4	20.0	SU
Typic Rhodustalf	22.5	31.3	17.8	23.9	SU
Typic Ochraqualf	45.1	38.5	34.9	39.5	VU
Aeric Ochraqualf	37.2	33.2	38.2	36.2	VU
Typic Ustorthent	48.6	38.4	42.6	43.2	VU
Lithic Ustorthent	60.1	44.1	44.8	49.7	VU
Aeric Fluvaquent	65.0	87.4	91.6	81.3	VU
Typic Ustipsamment	36.6	41.2	41.4	39.7	VU
Typic Chromustert	28.4	20.6	34.8	27.9	U
Chromic Haplustert	68.1	74.2	69.6	70.6	VU
Typic Haplustert	73.8	74.2	76.8	74.9	VU
Typic Haplustert	73.8	74.2	76.8	74.9	VU
Lithic Haplustoll	64.3	62.7	69.5	65.5	VU
Mean	45.2	44.4	46.4		

CD (P=0.05) to compare soil subgroup means: 1.4
soil depth means: 0.8
subgroup x depth: 0.6

VU= Very unstable; U = Unstable; SU = Somewhat unstable for 0-15, 15-30 and 30-150 cm soil depth were found 26.0, 23.0 and 22.5, respectively and no significant difference was observed between 15-30 and 30-150 cm soil depth values of EI, while significantly higher value of EI was observed of 0-15 cm soil depth. In general as the soil depth increases the EI decreases. The similar type of observation were also observed by Gupta et. al (1998); Jha and Rathore (1981).

Among Inceptisol subgroups in 0-15 cm soil depth the highest EI 43.86 was observed in Typic Haplustept followed by Vertic Ustochrept (41.62), Aeric Haplaquept (39.16) and Vertic Tropaquept 36.81 and lowest 15.41 was observed in Vertic Haplaquept. No significant difference was observed between Vertic Haplaquept and Typic Tropaquept. In 15-30 cm soil depth the highest EI value 42.54 was observed in Typic Haplustept and lowest 15.46 in Typic Tropaquept. No significant difference was observed between Aeric Tropaquept and Typic Ustochrept and in Vertic Haplaquept and Typic Tropaquept. In 30-150 cm soil depth the highest EI 39.90 again was observed in Typic Haplustept and lowest 13.66 was observed in Vertic Haplaquept. No significant diference was observed in Typic Ustropept and Typic Tropaquept.

Mean values of EI for Alfisol subgroups in 0-15 cm soil depth varied from 2.99 in Rhodic Paleustalf to 24.40 in Typic Paleustalf. No significant difference was observed in Ultic Paleustalf and Typic Rhodustalf and in Typic Ochraqualf Typic Haplustalf and Kandic Paleustalf. In 15-30 cm soil depth the highest EI 19.94 was observed in Aeric Ochraqualf and lowest 7.26 was in Typic Paleustalf. No significant difference was observed in Ultic Paleustalf and Typic Paleustalf, in Typic Rhodustalf and Kandic Paleustalf, in Typic Rhodustalf and Kandic Paleustalf, in Typic Rhodustalf and Typic Ochraqualf and in Typic Occhraqualf Aeric Ochraqualf and Typic Haplustalf.

Highest value of EI for Entisol subgroups in 0 – 15 cm soil depth 45.86 was observed in Typic Ustipsamment and lowest 32.27 was in Typic Ustorthent. No significant difference was observed in Aeric Fluvaquent and Typic Ustorthent. In 15-30 cm and 30-150 cm soil depth the highest EI 36.89 and 40.85 was observed in Aeric Fluvequent and lowest 22.89 and 21.12 were observed in Lithic Ustorthent and Typic Ustorthent. Significantly higher value of mean EI was found for 0-15cm soil depth. The similar type of observations were also observed by Sahi *et al.* (1997) for some soil series of Bihar and by Gupta *et al.* (1998) for Himachal Pradesh.

Among Vertisol subgroups highest values of EI for all the soil depth was found in Typic Haplstert and lowest were observed in Typic Hapustert followed by Chromic Haplustert and lowest were observed in Typic Chromustert. The erosion index of Lithic Haplustoll was 24.50in 0 – 15 cm soil depth and 31.37 in 30 –150 cm soil depth.

Table 8. Erosion index of dominating soil subgroups of eastern India

Soil subgroup	Erosion index				
	Soil depth (cm)			Mean EI	Category
	0- 15	15 -30	30 –150		
Vertic Haplaquept	15.41	16.52	13.66	15.20	M
Aeric Haplaquept	39.16	28.38	26.51	29.35	VH
Typic Tropaquept	15.66	15.46	16.96	16.03	H
Vertic Tropaquept	36.81	30.97	30.72	32.83	VH
Aeric Tropaquept	22.01	20.26	24.19	22.15	VH
Typic Ustochrept	17.86	20.13	19.48	19.16	H
Vertic Ustochrept	41.62	35.08	38.86	38.52	VH
Typic Ustropept	23.55	22.65	16.10	20.77	VH
Typic Haplustept	43.86	42.54	39.90	42.10	VH
Vertic Haplustept	28.38	23.57	24.77	25.58	VH
Typic Haplustalf	20.93	18.90	19.96	19.93	H
Typic Paleustalf	24.40	7.26	10.00	13.89	M
Ultic Paleustalf	14.47	7.68	8.29	10.15	L
Kandic Paleustalf	22.00	16.62	14.49	17.70	H
Rhodic Paleustalf	2.99	13.54	9.69	8.74	L
Typic Rhodustalf	15.00	17.53	9.14	13.89	M
Typic Ochraqualf	21.24	18.89	16.09	18.74	H
Aeric Ochraqualf	23.80	19.94	21.66	21.80	VH
Typic Ustorthent	32.27	24.47	21.12	25.95	VH
Lithic Ustorthent	35.48	22.89	24.40	27.59	VH
Aeric Fluvaquent	32.63	36.89	40.85	36.79	VH
Typic Ustipsamment	45.86	34.92	28.96	36.58	VH
Typic Chromustert	13.42	9.37	15.72	12.84	M
Chromic Haplustert	27.79	28.83	27.10	27.91	VH
Typic Haplustert	35.98	34.35	35.24	35.19	VH
Lithic Haplustoll	24.50	29.37	31.37	28.41	VH
Mean	26.0	23.0	22.5		
C D (P=0.05) to compare	soil subgroup means:	1.24			
	soil depth means:	0.74			
	subgroup x depth:	0.56			

Erosion Index (EI) of 0 –5, 6 – 10, 11-15, 16 –20 and > 20 were categories as very low, low, medium, high and very high. Out of 26 soil subgroups, 15 had very high category, 5 high, 4 medium and 2 comes under low category. Very high EI was observed in Aeric Haplaquept, Vertic Tropaquept, Aeric Tropaquept, Vertic Ustochrept, Typic Ustropept, Typic Haplustept, Vertic Haplustept, Aeric Ochraqualf, Typic Ustorthent, Lithic Ustorthent, Aeric Fluvaquent, Typic Ustipsamment, Chromic Haplustert, Typic Haplustert and Lithic Haplustoll subgroups, while high was observed in Typic Tropaquept, Typic Ustochrept, Typic Haplustalf, Kandic Paleustalf and Typic Ochraqualf subgroups. Medium EI was observed in Vertic Haplaquept, Typic Paleustalf, Typic Rhodustalf, Typic Chromustert subgroups and low EI was observed in Ultic Paleustalf and Rhodic Paleustalf subgroups.

4.5 Relationship between erosion index and other soil properties

The correlation co-efficient values presented in Table 9 reveal that sand and dispersion ratio had highly significant and positive relationship with erosion index (EI). It indicate that presence of high amount of sand fraction in the soil increase soil erodibility and similarly causes and factors which increase soil dispersion also increases soil erodibility. As the dispersion ratio increased, erosion index also increased indicating greater susceptibility of these soils to water erosion. A highly significant and negative relationship of EI were observed with clay, silt+clay, maximum water holding capacity and erosion index (EI). Negative correlation with clay, silt+clay, and maximum water holding capacity suggested that soil erodability decreases with increase in clay, silt + clay and maximum water holding capacity. Similar type of observations were also observed by Sharma *et al.* (1980), Sharma *et al.* (1987) and Singh and Kundu (2005a).

Table 9. Correlation coefficient (r) of erosion index with different properties of soil

Soil property	**r**
Sand	0.0.402**
Clay	- 0.518**
Silt + Clay	- 0.411**
Clay ratio	0.534**
Dispersion ratio	0.792**
EC_2	- 0.334**
MWC (Maximum water holding capacity)	- 0.357**

**Significant at 1% level

Soil erosion has been identified as a potential threat to sustainability of the livelihood system of the people in the eastern India. Erosion indices (Dispersion ratio, DR and erosion index, EI) were measured for 26 dominating soil subgroups of eastern India. A highly significant and negative relationship of erosion index with clay, silt + clay, maximum water holding capacity and highly significant, and positive relationship with sand and dispersion ratio were observed. As the dispersion ratio increased, erosion index also increased indicating susceptibility of these soils to water erosion.

4.6 Water Retention Characteristics

Important hydraulic characteristics of the soils are presented in Table 10. At 0.033 MPa, highest water was retained by Typic Ustochrept (0.556m^3 m^{-3}) followed by Vertic Haplaquept, Aeric Fluvaquent, Vertic Haplustept, Typic Tropaquept and Aeric Tropaquept. Water retention was

Table 10. Salient hydraulic characteristics of dominant soil subgroups of eastern India

Name of the soil subgroup	Soil depth (cm)	θ (cm^3/ cm3) (0.033Mpa)	θ (cm^3/ cm3) (1.5 Mpa)	Available water content (cm^3/cm^3)	K_s (cm/ hr)	ψ_e (cm)	b
Vertic Haplaquept	0-30	0.487	0.255	0.232	0.018	70.0	5.878
	30-60	0.540	0.288	0.252	0.014	90.4	6.369
	60-90	0.542	0.298	0.244	0.013	88.9	6.244
Aeric Haplaquept	0-30	0.306	0.102	0.204	0.147	28.7	3.619
	30-60	0.332	0.130	0.202	0.274	26.7	4.422
	60-90	0.360	0.173	0.187	0.317	20.2	5.494
Typic Tropaquept	0-30	0.460	0.208	0.252	0.021	66.7	4.928
	30-60	0.470	0.248	0.222	0.014	59.7	6.192
	60-90	0.485	0.261	0.224	0.012	55.7	6.456
Vertic Tropaquept	0-30	0.155	0.074	0.081	0.079	13.2	3.745
	30-60	0.189	0.093	0.096	0.055	14.4	4.205
	60-90	0.215	0.105	0.110	0.051	14.2	4.573
Aeric Tropaquept	0-30	0.432	0.189	0.244	0.025	67.7	4.363
	30-60	0.435	0.198	0.237	0.020	59.9	5.020
	60-90	0.461	0.215	0.246	0.011	80.3	4.775
Typic Ustochrept	0-30	0.521	0.240	0.281	0.023	125.9	5.187
	30-60	0.559	0.255	0.304	0.021	177.2	5.541
	60-90	0.609	0.286	0.323	0.02	189.5	5.804
Vertic Ustochrept	0-30	0.261	0.099	0.162	0.072	22.7	3.828
	30-60	0.337	0.147	0.190	0.018	53.1	4.272
	60-90	0.370	0.185	0.185	0.015	31.0	5.226
Typic Ustropept	0-30	0.344	0.139	0.206	0.821	34.1	4.325
	30-60	0.396	0.169	0.227	0.446	44.1	4.671
	60-90	0.432	0.190	0.242	0.012	66.4	4.981

Name of the soil subgroup	Soil depth (cm)	θ (cm^3/ cm3) (0.033Mpa)	θ (cm^3/ cm3) (1.5 Mpa)	Available water content (cm^3/cm^3)	K_s (cm/ hr)	ψ_e (cm)	b
Typic Haplustept	0-30	0.322	0.120	0.202	1.076	46.6	4.050
	30-60	0.332	0.134	0.198	0.871	45.1	4.316
	60-90	0.370	0.173	0.197	0.302	40.0	5.071
Vertic Haplustept	0-30	0.462	0.239	0.223	0.121	89.5	6.329
	30-60	0.501	0.268	0.233	0.078	80.5	6.668
	60-90	0.528	0.303	0.225	0.046	100.8	7.448
Typic Haplustalf	0-30	0.436	0.177	0.259	0.119	53.9	4.397
	30-60	0.369	0.159	0.210	0.103	40.0	4.487
	60-90	0.405	0.182	0.223	0.100	41.3	4.903
Typic Paleustalf	0-30	0.314	0.158	0.157	0.742	23.2	5.174
	30-60	0.365	0.205	0.160	1.712	17.4	6.503
	60-90	0.395	0.229	0.166	1.152	18.3	6.726
Ultic Paleustalf	0-30	0.207	0.081	0.126	0.841	20.1	3.769
	30-60	0.241	0.122	0.119	0.816	6.7	5.090
	60-90	0.257	0.131	0.126	1.293	9.9	5.168
Kandic Paleustalf	0-30	0.265	0.159	0.106	0.713	16.8	5.487
	30-60	0.313	0.173	0.140	0.269	23.0	5.423
	60-90	0.318	0.173	0.145	0.223	23.2	5.502
Rhodic Paleustalf	0-30	0.315	0.173	0.142	1.01	36.9	4.909
	30-60	0.269	0.164	0.105	0.927	23.3	5.305
	60-90	0.227	0.126	0.101	0.862	36.4	4.394
Typic Rhodustalf	0-30	0.274	0.142	0.132	0.563	35.1	4.407
	30-60	0.356	0.185	0.171	0.514	32.1	5.362
	60-90	0.363	0.173	0.190	0.488	41.9	5.071
Typic Ochraqualf	0-30	0.385	0.190	0.195	0.061	37.4	5.426
	30-60	0.421	0.242	0.179	0.016	31.6	6.387
	60-90	0.426	0.234	0.192	0.015	35.9	6.214
Aeric Ochraqualf	0-30	0.359	0.110	0.249	0.235	69.1	3.369
	30-60	0.336	0.126	0.210	0.123	48.3	4.025
	60-90	0.352	0.172	0.180	0.078	35.3	5.037
Typic Ustorthent	0-30	0.310	0.132	0.178	0.073	40.2	4.211
	30-60	0.342	0.168	0.174	0.056	40.4	4.978
	60-90	0.394	0.168	0.226	0.037	76.5	5.007
Lithic Ustorthent	0-30	0.395	0.177	0.218	0.086	31.3	5.051
	30-60	0.401	0.202	0.199	0.072	24.1	5.684
Aeric Fluvaquent	0-30	0.426	0.206	0.220	0.003	98.7	5.307
	30-60	0.498	0.262	0.236	0.004	69.5	5.822
	60-90	0.568	0.300	0.268	0.008	94.2	6.494
Typic Ustipsamment	0-30	0.119	0.053	0.066	2.862	1.2	4.792
	30-60	0.158	0.090	0.068	0.652	2.5	5.209
	60-90	0.188	0.104	0.084	0.544	2.7	5.745
Typic Chromustert	0-30	0.385	0.202	0.183	0.595	46.5	5.321
	30-60	0.419	0.225	0.194	0.167	50.5	5.767
	60-90	0.465	0.241	0.224	0.149	60.3	5.423
Chromic Haplustert	0-30	0.364	0.194	0.170	0.097	38.3	6.231
	30-60	0.391	0.204	0.188	0.047	45.9	6.004
	60-90	0.374	0.198	0.176	0.042	40.3	6.124

Name of the soil subgroup	Soil depth (cm)	θ (cm^3/ cm3) (0.033Mpa)	θ (cm^3/ cm3) (1.5 Mpa)	Available water content (cm^3/cm^3)	K_s (cm/ hr)	ψ_e (cm)	b
Typic Haplustert	0-30	0.447	0.226	0.221	0.266	36.4	5.841
	30-60	0.403	0.207	0.196	0.322	29.9	5.867
	60-90	0.387	0.184	0.203	0.164	36.1	5.600
Lithic Haplustoll	0-30	0.302	0.111	0.192	0.797	102.9	4.207
	30-60	0.421	0.158	0.264	0.533	103.6	4.660
	60-90	0.423	0.156	0.267	0.412	100.0	4.621

lowest by Typic Ustipsamment (0.158 $m^3\ m^{-3}$). Water retention by the other soil subgroups varied from 0.438 to 0.184 $m^3\ m^{-3}$. Similarly at 1.5 MPa, highest amount of water was retained by Vertic Haplaquept, Typic Ustochrept and the lowest by Typic Ustipsamment. Highest available water at all the depths was found in Typic Ustochrept followed by Vertic Haplaquept, Typic Tropaquept and Aeric Tropaquept. Lowest available water content was found in Typic Ustipsamment. In comparison to Alfisol and Entisol more water was retained by Inceptisol, Vertisols and Mollisol soil subgroups at 0.033 and 1.5 Mpa. Functional relationship between ψ and θ are presented in Table 11 and moisture retention curve are presented in Fig.2 a, b, c and d.

Table 11. Functional relations between water content (θ) and matric potentials (ψ) in dominant soil subgroups of eastern India

Name of the soil subgroup	Functional relation between θ and ψ (ψ in m, θ in $m^3 m^{-3}$)
AericTropaquept	$\text{Log}\ \Psi = -4.676\ \text{Log}\ \theta - 1.158$, $R^2 = 0.997$
Aeric Haplaquept	$\text{Log}\ \Psi = -4.445\ \text{Log}\ \theta - 1.692$, $R^2 = 0.973$
Typic Ustochrept	$\text{Log}\ \Psi = -5.485\ \text{Log}\ \theta - 0.793$, $R^2 = 0.926$
Vertic Haplaquept	$\text{Log}\ \Psi = -6.249\ \text{Log}\ \theta - 1.211$, $R^2 = 0.986$
Vertic Tropaquept	$\text{Log}\ \Psi = -4.238\ \text{Log}\ \theta - 2.363$, $R^2 = 0.945$
Typic Ustropept	$\text{Log}\ \Psi = -4.679\ \text{Log}\ \theta - 1.362$, $R^2 = 0.988$
Typic Tropaquept	$\text{Log}\ \Psi = -5.845\ \text{Log}\ \theta - 1.385$, $R^2 = 0.988$
Vertic Ustochrept	$\text{Log}\ \Psi = -4.613\ \text{Log}\ \theta - 1.731$, $R^2 = 0.988$
Typic Haplustept	$\text{Log}\ \Psi = -4.329\ \text{Log}\ \theta - 1.449$, $R^2 = 0.991$
Vertic Haplustept	$\text{Log}\ \Psi = -6.649\ \text{Log}\ \theta - 1.510$, $R^2 = 0.976$
Ultic Paleustalf	$\text{Log}\ \Psi = -4.643\ \text{Log}\ \theta - 2.395$, $R^2 = 0.972$
Typic Paleustalf	$\text{Log}\ \Psi = -6.063\ \text{Log}\ \theta - 2.251$, $R^2 = 0.988$

Name of the soil subgroup	Functional relation between θ and ψ (ψ in m, θ in m^3m^{-3})
Rhodic Paleustalf	$\text{Log}\,\Psi = -5.016\,\text{Log}\,\theta - 1.872$, $R^2 = 0.939$
Typic Rhodustalf	$\text{Log}\,\Psi = -5.127\,\text{Log}\,\theta - 1.677$, $R^2 = 0.964$
Typic Ochraqualf	$\text{Log}\,\Psi = -5.884\,\text{Log}\,\theta - 1.752$, $R^2 = 0.997$
Aeric Ochraqualf	$\text{Log}\,\Psi = -3.919\,\text{Log}\,\theta - 1.278$, $R^2 = 0.991$
Typic Haplustalf	$\text{Log}\,\Psi = -4.658\,\text{Log}\,\theta - 1.481$, $R^2 = 0.977$
Kandic Paleustalf	$\text{Log}\,\Psi = -5.650\,\text{Log}\,\theta - 2.001$, $R^2 = 0.969$
Aeric Fluvaquent	$\text{Log}\,\Psi = -5.869\,\text{Log}\,\theta - 1.344$, $R^2 = 0.979$
Typic Ustipamment	$\text{Log}\,\Psi = -5.272\,\text{Log}\,\theta - 3.664$, $R^2 = 0.985$
Typic Ustorthent	$\text{Log}\,\Psi = -4.872\,\text{Log}\,\theta - 1.682$, $R^2 = 0.994$
Lithic Ustorthent	$\text{Log}\,\Psi = -5.433\,\text{Log}\,\theta - 1.811$, $R^2 = 0.981$
Typic Chromustert	$\text{Log}\,\Psi = -5.605\,\text{Log}\,\theta - 1.366$, $R^2 = 0.979$
Chromic Haplustert	$\text{Log}\,\Psi = -5.871\,\text{Log}\,\theta - 1.744$, $R^2 = 0.945$
Typic Haplustert	$\text{Log}\,\Psi = -5.478\,\text{Log}\,\theta - 1.401$, $R^2 = 0.970$
Lithic Haplustoll	$\text{Log}\,\Psi = -4.588\,\text{Log}\,\theta - 1.426$, $R^2 = 0.935$

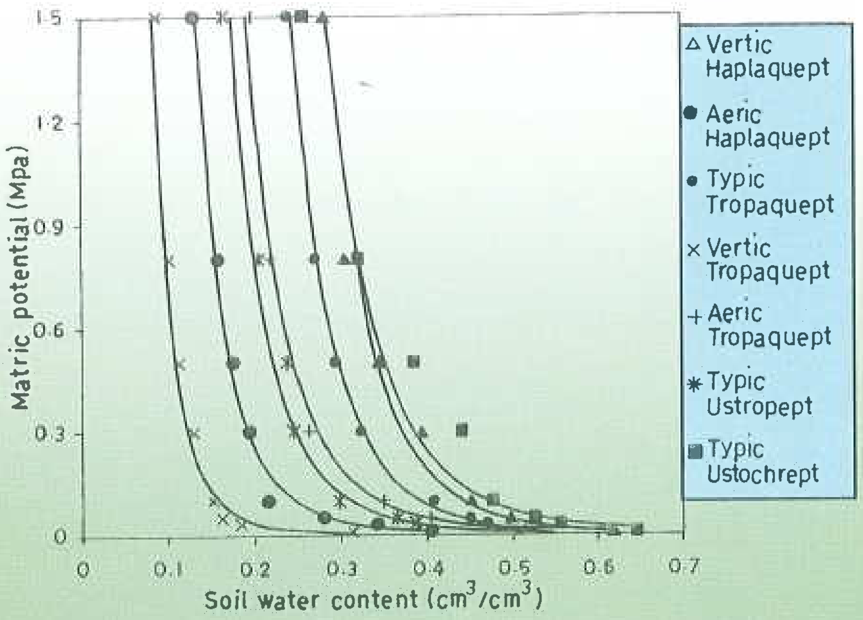


Fig. 2a Matric potential as a function of soil water content in different soil

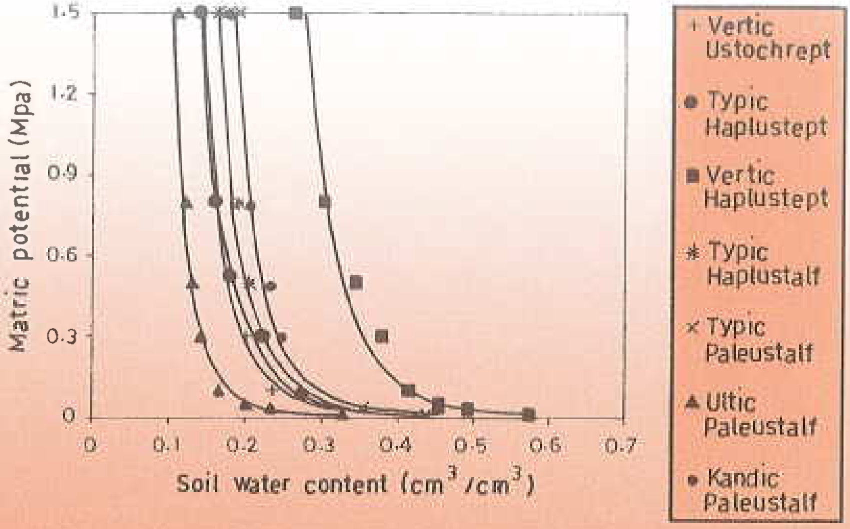


Fig. 2b Matric potential as a function of soil water content in different soil

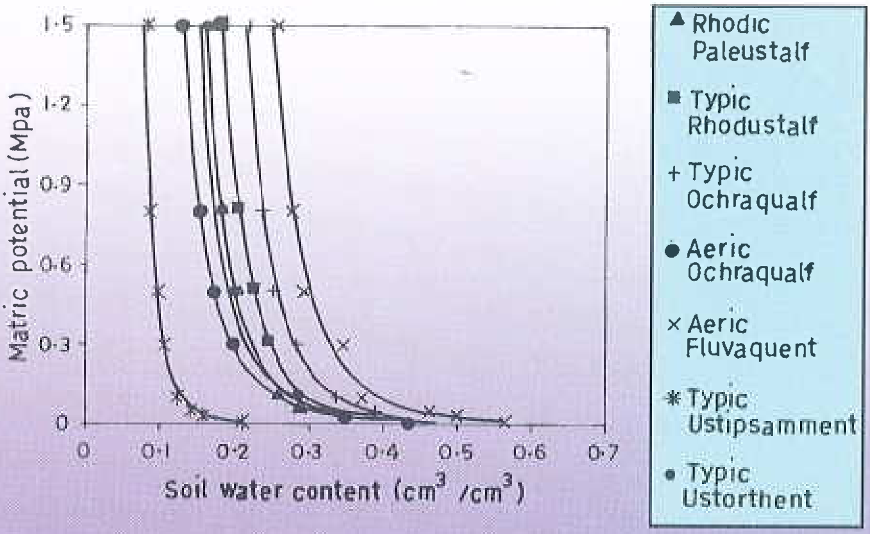


Fig. 2c Matric potential as a function of soil water content in different soil

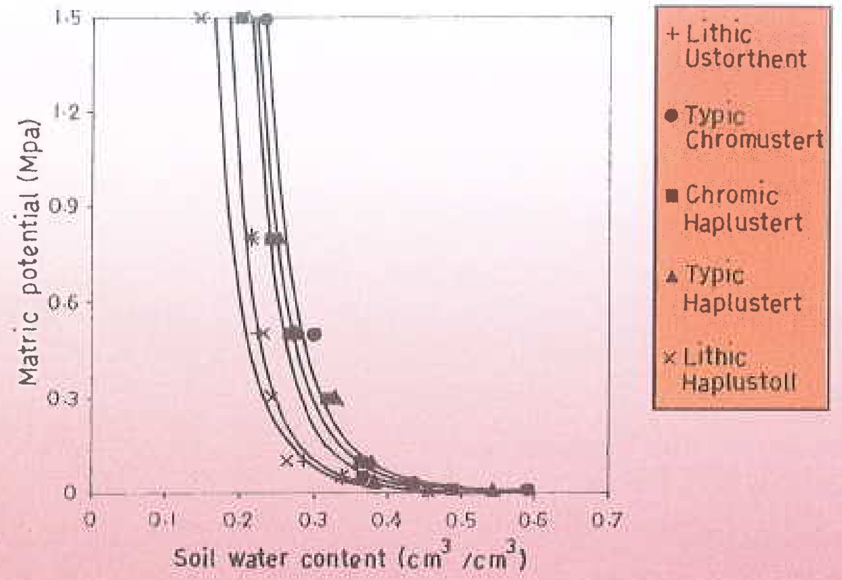


Fig. 2d Matric potential as a function of soil water content in different soil

4.7 Profile water storage capacity

Profile water storage capacity of <5, 5-10, 10-15, 15-20, and >20 cm m^{-1} soil depth were categorised as very low, low, medium, high and very high, respectively (Rao and Prasadini 1998). Out of 26 soil subgroups, 9 had very high, 7 high to very high, 3 high, 3 medium to high, 2 medium and 1 each had low to medium and low water storage capacity. Very high profile water storage capacity was observed in Vertic Haplaquept, Typic Tropaquept, Aeric Tropaquept, Typic Ustochrept, Vertic Haplustept, Typic Haplustalf, Lithic Ustorthent, Aeric Fluvaquent and Typic Haplustert. Very high to high profile water storage capacity was observed in Aeric Haplaquept, Typic Ustropept, Typic Ochraqualf, Aeric Ochraqualf, Typic Ustorthent, Typic Chromustert and Lithic Haplustoll. The storage capacity was high in Typic Haplustept, Typic Paleustalf and Chromic Haplustert; medium in Ultic Paleustalf and Rhodic Paleustalf ; and low in Typic Ustipsamment. The highest profile water storage capacity of 27.8 to 28.4 cm m^{-1} was found in Typic Ustochrept and the lowest of 8.9 to 9.8 cm m^{-1} was found in Typic Ustipsamment (Table 12).

Out of 10 soil subgroups in Inceptisols, 1 had low to medium, 1 medium to high, 1 high, 2 high to very high and 5 had very high water storage capacity (Table 12). Very high profile water storage capacity was observed in Vertic Haplaquept, Typic Tropaquept, Aeric Tropaquept, Typic Ustochrept and Vertic Haplustept. The storage capacity was high to very high in Aeric Haplaquept and Typic Ustropept, high in Typic Haplustept and medium to high in Vertic Ustochrept. Low to medium profile water storage capacity was observed in Vertic Tropaquept

Table 12. Moisture content at field capacity, wilting point and water storage capacity of the dominating soil subgroups in the eastern region.

Name of the soil subgroup	Water content at field capacity ($cm^3 cm^{-3}$)	Water content at wilting point ($cm^3 cm^{-3}$)	Profile water storage capacity (cm m^{-1} depth)	Category for profile water capacity
Vertic Haplaquept	0.452-0.542	0.231-0.312	22.1 - 23.0	Very high
Aeric Haplaquept	0.297-0.409	0.101-0.173	19.6 - 23.6	High - Very high
Typic Tropaquept	0.450-0.487	0.201-0.272	24.9 - 21.5	Very high
Vertic Tropaquept	0.152-0.215	0.071-0.105	8.1 - 11.0	Low - Medium
Aeric Tropaquept	0.415-0.449	0.169-0.215	23.4 - 24.6	Very high
Typic Ustropept	0.328-0.432	0.136-0.192	19.2 - 24.0	High - Very high
Typic Ustochrept	0.516-0.570	0.238-0.286	27.8 - 28.4	Very high
Vertic Ustochrept	0.210-0.377	0.070-0.196	14.0 - 18.1	Medium - High
Typic Haplustept	0.307 – 0.370	0.114 – 0.173	19.3 - 19.7	High
Vertic Haplustept	0.449 – 0.528	0.237 – 0.303	21.2 - 22.5	Very high
Typic Haplustalf	0.369-0.442	0.159-0.183	21 - 25.9	Very high
Typic Paleustalf	0.298-0.395	0.134-0.229	16.4 - 16.6	High
Ultic Paleustalf	0.170-0.259	0.060-0.139	11.0- 12.0	Medium
Kandic Paleustalf	0.243-0.345	0.139-0.179	10.4 - 16.6	Medium -High
Rhodic Paleustalf	0.227-0.330	0.126-0.189	10.1 - 14.1	Medium
Typic Rhodustalf	0.216-0.408	0.084-0.216	13.2 - 19.2	Medium - High
Typic Ochraqualf	0.379-0.453	0.184-0.242	19.5 - 21.1	High – Very high
Aeric Ochraqualf	0.336-0.352	0.098-0.172	18.0 - 23.8	High - Very high
Aeric Fluvaquent	0.399-0.578	0.186-0.309	21.3 - 26.9	Very high
Typic Ustipsamment	0.130-0.209	0.041-0.111	8.9 - 9.8	Low
Typic Ustorthent	0.291-0.407	0.129-0.205	16.2 - 20.2	High – Very high
Lithic Ustorthent	0.389-0.411	0.174-0.206	20.5 - 21.5	Very high
Typic Chromustert	0.382-0.483	0.201-0.253	18.1 - 23.0	High -Very high
Chromic Haplustert	0.359 – 0.401	0.191 – 0.208	16.8 - 19.3	High
Typic Haplustert	0.387 – 0.467	0.184 – 0.237	20.3 - 23.0	Very high
Lithic Haplustoll	0.243 – 0.438	0.082 – 0.160	16.1 -27.8	High - Very high

(Table 12). The highest profile water storage capacity of 27.8 – 28.4 cm m^{-1} was found in Typic Ustochrept and the lowest of 8.1 – 11.0 cm m^{-1} was observed in Vertic Tropaquept.

Out of 8 soil subgroups of Alfisols, 1 had very high, 2 high to very high, 1 high, 2 medium to high and 2 had medium water storage capacity. Very high profile water storage capacity was observed in Typic Haplustalf and high to very high was observed in Typic Ochraqualf and Aeric Ochraqualf. The storage capacity was high in Typic Paleustalf and medium to high in Kandic Paleustalf and Typic Rhodustalf. Medium profile water storage capacity was observed in Ultic Paleustalf and Rhodic Paleustalf. The highest profile water storage capacity of 21.0 to 25.9 cm m^{-1} was found in Typic Haplustalf. In Entisols, very high profile water storage capacity varying from 20.5 to 26.9 cm m^{-1} was observed in Lithic Ustorthent and Aeric Fluvaquent. The storage capacity was high to very high in Typic Ustorthent and low in Typic Ustipsamment (Table 12). In Vertisols very high profile water storage capacity ranging from 20.3 to 23.0 cm $m^{-1}$was observed in Typic Haplustert. The storage capacity was high to very high in Typic Chromustert and high in Chromic Haplustert (range: 16.8 to 23.0 cm m^{-1}). In Lithic Haplustoll subgroup of Mollisol order the profile water storage capacity was high to very high and it varied from 16.1 to 27.8 cm m^{-1} (Table 12).

4.8 Relationship between profile water storage capacity and other soil properties

Simple correlation coefficients (r) were worked out between sand, silt, clay, bulk density, organic carbon, calcium carbonate and cation exchange capacity of soils and water retained at field capacity, wilting point and available water capacity. The results revealed (Table 13) that moisture retention at field capacity, wilting point and available water in these soils was positively influenced by silt, clay, organic carbon, calcium carbonate and cation exchange capacity; whereas negatively influenced by 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) and Singh and Kundu (2005b).

Stepwise regression analysis was carried out to test the effectiveness of the influence of variables namely sand, silt, clay, bulk density, electrical conductivity, organic carbon, calcium carbonate and cation exchange capacity on water retention at field capacity, wilting point and available water. All the variables put together accounted for a variation of 86.8, 89.3 and 69.1 per cent for the water retention at field capacity, wilting point and available water, respectively (Table 14). Sand, silt, clay, bulk density, electrical conductivity, organic carbon and calcium carbonate accounted for 85.8 per cent variation and sand, silt and clay together accounted for 82.0 per cent variation in water retention at field capacity. For moisture retention at wilting point; sand, silt, clay, bulk density, electrical conductivity, organic carbon and calcium carbonate together accounted for 88.7 per cent variation; sand, silt and clay together accounted for 85.8 per cent variation, and sand and silt together accounted for 34.2 per cent variation (Table 14). Similar types of observations for alluvial soils were also made by Singh *et al.* (1992) and Singh and Kundu (2005). For prediction of available soil water; sand, silt and clay together accounted for 61.0 per cent variation; sand, silt, clay, bulk density, electrical conductivity, organic carbon and calcium carbonate together accounted for 68.2 per cent; and sand and silt together accounted for 48.7 per cent variation. Hence, available water could not be predicted as accurately as water retention at field capacity and wilting point. It was better to estimate available water from the difference of the predicted values of water retention at field capacity and wilting point. The equations for predicting moisture retention at field capacity and wilting points are given below:

a) Including all variables:

$$\theta_{fc} = -0.001 + 0.001\text{sand \%} + 0.004\text{silt \%} + 0.006\text{ clay \%} - 0.034\text{ bulk density (Mg cm}^{-3}\text{)} + 0.032\text{ EC (dS/m)} + 0.067\text{ OC \%} - 007\text{ CaCO}_3\text{ \%} + 0.002\text{ CEC [cmol (p}^{+}\text{) kg}^{-1}\text{]}, R^2 = 0.868 \text{ ---------- } (15)$$

$$\theta_{wp} = -0.195 + 0.001\text{sand \%} + 0.002\text{silt \%} + 0.005\text{ clay \%} + 0.042\text{ bulk density (Mg cm}^{-3}\text{)} + 0.020\text{ EC (dS/m)} - 0.002\text{ OC \%} + 001\text{ CaCO}_3\text{ \%} + 0.001\text{ CEC [cmol (p}^{+}\text{) kg}^{-1}\text{]}, R^2 = 0.868 \text{ ---------- } (16)$$

b) *Including sand, silt and clay only:*

$$\theta_{fc} = -0.119 + 0.002\text{sand \%} + 0.005\text{silt \%} + 0.008\text{ clay \%}, R^2 = 0.820 \text{ ——— } (17)$$

$$\theta_{wp} = -0.161 + 0.002\text{sand \%} + 0.002\text{silt \%} + 0.006\text{ clay \%}, R^2 = 0.858 \text{ ——— } (18)$$

where, θ_{fc} = Water content at field capacity ($cm^3\ cm^{-3}$) and

θ_{wp} = Water content at wilting point ($cm^3\ cm^{-3}$)

The coefficient of determination with equation 3 and 4 was 0.817 and 0.835, respectively, indicating that soil water retention at field capacity and wilting point can be predicted by using easily measured soil properties like sand, silt and clay data with satisfactory level of accuracy.

Table 13. Matrix of simple correlation coefficients

	Sand (%)	Silt (%)	Clay (%)	Bulk ensity (Mg cm^{-3})	EC$_2$ (dS/m)	OC (%)	CaCO$_3$ (%)	CEC (cmol (p$^+$) kg^{-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										
Silt (%)	-0.77**	1									
Clay (%)	-0.70**	0.53**	1								
Bulk density (Mg cm^{-3})	0.52**	-0.34**	-0.20	1							
EC$_2$ (dS/m)	-0.11	0.16	0.22	-0.05	1						
OC (%)	0.02	0.11	0.42**	0.04	0.13	1					
CaCO$_3$ (%)	-0.41**	0.48**	0.48**	-0.06	0.22	0.21	1				
CEC (cmol (p$^+$) kg^{-1})	-0.62**	0.54**	0.79**	-0.31**	0.35**	0.35**	0.45**	1			
θ at field capacity (cm^3 cm^{-3})	-0.64**	0.65**	0.87**	-0.23	0.37**	0.47**	0.48**	0.81**	1		
θ at wilting point (cm^3 cm^{-3})	-0.56**	0.54**	0.90**	-0.10	0.39**	0.45**	0.50**	0.79**	0.93**	1	
Available water capacity (cm^{3}cm^{-3})	-0.61**	0.69**	0.67**	-0.33**	0.30**	0.42**	0.39**	0.68**	0.90**	0.70**	1

** significant at 5 % level of confidence

Table 14. Linear regression coefficients 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 cm^{-3})	EC_2 (dS/m)	OC (%)	$CaCO_3$ (%)	CEC [cmol (p$^+$) kg^{-1}]	
For field capacity									
-0.001	0.001	0.004	0.006	-0.034	0.032	0.067	-0.007	0.002	0.868
0.055	0.001	0.004	0.007	-0.083	0.038	0.070	-0.006		0.858
0.068	0.001	0.004	0.007	-0.091	0.037	0.070			0.857
0.073	0.002	0.005	0.008	-0.134	0.037				0.850
0.077	0.002	0.005	0.009	-0.157					0.825
-0.119	0.002	0.005	0.008						0.820
0.351	-0.002	0.005							0.475
0.525	-0.004								0.413
For wilting point									
-0.195	0.001	0.002	0.005	0.042	0.020	-0.002	0.001	0.001	0.893
-0.167	0.001	0.002	0.006	0.018	0.024	-0.001	0.001		0.887
-0.169	0.001	0.002	0.006	0.019	0.024	-0.001			0.887
-0.169	0.001	0.002	0.006	0.019	0.024				0.887
-0.166	0.002	0.002	0.006	0.004					0.858
-0.161	0.002	0.002	0.006						0.858
0.188	-0.001	0.002							0.342
0.260	-0.002								0.313
For available water									
17.15	0.011	0.265	0.103	-8.341	1.180	6.676	-0.587	0.096	0.691
19.782	0.014	0.278	0.158	-10.687	1.486	6.842	-0.529		0.682
21.063	0.013	0.263	0.148	-11.428	1.410	6.780			0.678
21.525	0.086	0.310	0.252	-15.600	1.360				0.648
21.673	0.097	0.324	0.271	-16.455					0.633
1.175	0.047	0.307	0.240						0.610
14.643	-0.059	0.302							0.487
26.267	-0.183								0.368

4.9 Water Transmission Characteristics

Data on penetrability (P), intrinsic penetrability (Pi), sorptivity (S), weighted mean diffusivity (D) and intrinsic weighted mean diffusivity (Di) of water in the soil are presented in Table 15. Penetrability and intrinsic penetrability in the soil followed similar patterns. The penetrability values were found to be highest in Typic Rhodustalf and lowest in Aeric Fluvaquent. The sorptivity was highest in Typic Paleustalf (1.01×10^{-3} $ms^{-1/2}$) followed by Typic Ustropept ($8.82 \text{ X } 10^{-4} ms^{-1/2}$) and Lithic Haplustoll ($7.89 \times 10^{-4} ms^{-1/2}$). The lowest sorptivity ($7.83 \text{ X } 10^{-5}$ $ms^{-1/2}$) was found in Aeric Fluvaquent.

Lowest weighted mean diffusivity (2.79×10^{-9} ms^{-1}) as well as intrinsic weighted mean diffusivity (4.23×10^{-11} m) was found in Aeric Fluvaquent while Typic Paleustalf had the highest weighted mean diffusivity (3.62×10^{-6} ms^{-1}) as well as intrinsic weighted mean diffusivity (5.05×10^{-8} m). Functional relationship between soil water diffusivity and moisture content, and hydraulic conductivity and moisture content showed exponential relationship. Both the parameters, soil water diffusivity and conductivity increased exponentially as moisture content increased and decreased with decrease in their water content. However, magnitude of the change in $K(\theta)$ and $D(\theta)$ with soil water content varied with soil type. Functional relationship between soil water diffusivity, hydraulic conductivity and water content are given in Table 16. The values of constant Do and exponent β for $D(\theta)$ and Ko and exponent β^{o} for $K(\theta)$ are given in Table 16. The values of β varied from 4.508 to 16.948. The highest was observed for Vertic Ustochrept and lowest for Aeric Fluvaquent, values of β^{o} varied from 4.771for Lithic Haplustoll to 17.742 for Vertic Ustochrept. Average profile unsaturated hydraulic conductivity and soil water diffusivity are presented in Fig. 3a,b,c,d and 4a,b,c,d.

Table 15. Values of the penetrability (P) intrinsic penetrability (Pi), sorptivity (S), weighted mean diffusivity (D) and intrinsic weighted mean diffusivity (Di)

Name of the soil subgroup	P ($ms^{-1/2}$)	Pi ($m^{1/2}$)	S ($ms^{-1/2}$)	$\bar{D}$ (ms^{-1})	Di (m)
AericTropaquept	5.30×10^{-4}	6.23×10^{-5}	2.43×10^{-4}	1.54×10^{-7}	1.88×10^{-9}
Aeric Haplaquept	2.15×10^{-3}	2.56×10^{-4}	7.79×10^{-4}	2.35×10^{-6}	3.17×10^{-8}
Typic Ustochrept	4.14×10^{-4}	4.86×10^{-5}	1.90×10^{-4}	1.12×10^{-7}	1.36×10^{-9}
Vertic Haplaquept	4.32×10^{-4}	5.06×10^{-5}	2.05×10^{-4}	3.23×10^{-7}	4.43×10^{-9}
Vertic Tropaquept	7.15×10^{-4}	8.37×10^{-5}	5.85×10^{-4}	3.02×10^{-7}	2.29×10^{-9}
Typic Ustropept	9.17×10^{-4}	1.07×10^{-4}	8.82×10^{-4}	6.17×10^{-7}	8.45×10^{-9}
Typic Tropaquept	3.76×10^{-4}	4.41×10^{-5}	2.72×10^{-4}	1.85×10^{-7}	2.53×10^{-9}
Vertic Ustochrept	4.53×10^{-4}	4.63×10^{-5}	1.84×10^{-4}	1.48×10^{-7}	2.03×10^{-9}
Typic Haplustept	7.26×10^{-4}	1.03×10^{-4}	7.72×10^{-4}	5.14×10^{-7}	7.34×10^{-9}
Vertic Haplustept	4.35×10^{-4}	4.86×10^{-5}	2.45×10^{-4}	3.13×10^{-7}	4.23×10^{-9}
Ultic Paleustalf	2.58×10^{-3}	3.10×10^{-4}	6.47×10^{-4}	2.82×10^{-6}	3.62×10^{-8}
Typic Paleustalf	2.43×10^{-3}	2.82×10^{-4}	1.01×10^{-3}	3.62×10^{-6}	5.05×10^{-8}
Rhodic Paleustalf	2.35×10^{-3}	2.75×10^{-4}	9.73×10^{-4}	3.41×10^{-6}	4.56×10^{-8}
Typic Rhodustalf	2.80×10^{-3}	3.26×10^{-4}	6.46×10^{-4}	1.42×10^{-6}	2.35×10^{-8}
Typic Ochraqualf	3.98×10^{-4}	4.66×10^{-5}	3.99×10^{-4}	9.44×10^{-8}	1.29×10^{-9}
Aeric Ochraqualf	9.66×10^{-4}	1.13×10^{-4}	5.88×10^{-4}	3.93×10^{-7}	3.62×10^{-9}
Typic Haplustalf	8.00×10^{-4}	9.37×10^{-5}	5.08×10^{-4}	1.13×10^{-7}	3.72×10^{-9}
Kandic Paleustalf	1.04×10^{-3}	1.22×10^{-4}	4.85×10^{-4}	3.37×10^{-7}	4.61×10^{-9}
Aeric Fluvaquent	7.39×10^{-5}	8.75×10^{-6}	7.83×10^{-5}	2.79×10^{-9}	4.23×10^{-11}
Typic Ustipamment	2.44×10^{-3}	2.86×10^{-4}	7.85×10^{-4}	3.39×10^{-6}	4.65×10^{-8}
Typic Ustorthent	9.43×10^{-4}	1.10×10^{-4}	4.17×10^{-4}	6.26×10^{-7}	8.57×10^{-9}
Lithic Ustorthent	5.65×10^{-4}	6.61×10^{-5}	2.83×10^{-4}	1.23×10^{-7}	1.69×10^{-9}
Typic Chromustert	4.71×10^{-4}	5.52×10^{-5}	2.80×10^{-4}	1.63×10^{-7}	2.23×10^{-9}
Chromic Haplustert	2.47×10^{-4}	2.89×10^{-5}	2.17×10^{-4}	3.21×10^{-8}	4.57×10^{-10}
Typic Haplustert	5.26×10^{-4}	6.14×10^{-5}	4.18×10^{-4}	2.12×10^{-7}	2.88×10^{-9}
Lithic Haplustoll	7.01×10^{-4}	8.22×10^{-5}	7.89×10^{-4}	2.79×10^{-7}	3.82×10^{-9}

Table 16. **Functional relationship between soil water diffusivity (D), hydraulic conductivity (K) and water content (θ)**

Name of the soil subgroup	$D(\theta) = D_0 \exp(\beta\theta)$ (m^2s^{-1})	R^2	$K(\theta) = K_0 \exp(\beta^0\theta)$ ($m\ s^{-1}$)	R^2
AericTropaquept	4.00 x10^{-9} exp (10.506 θ)	0.923	5.00 x10^{-14} exp (10.116 θ)	0.918
Aeric Haplaquept	3.00 x10^{-8} exp (11.909 θ)	0.983	2.00 x10^{-12} exp (11.271 θ)	0.925
Typic Ustochrept	9.00 x10^{-10} exp (10.842 θ)	0.926	4.00 x10^{-15} exp (11.435 θ)	0.927
Vertic Haplaquept	2.00 x 10^{-9} exp (12.754 θ)	0.943	3.00 x10^{-15} exp (13.459 θ)	0.932
Vertic Tropaquept	9.00 x10^{-9} exp (14.32 θ)	0.978	1.00 x10^{-12}exp (13.988 θ)	0.968
Typic Ustropept	1.00 x10^{-8} exp (11.18 θ)	0.946	6.00 x10^{-13}exp (9.784 θ)	0.9763
Typic Tropaquept	2.00 x10^{-9} exp (10.718 θ)	0.915	5.00 x10^{-14}exp (10.116 θ)	0.918
Vertic Ustochrept	5.00 x10^{-9}exp (16.948 θ)	0.961	3.00 x10^{-12} exp (17.678 θ)	0.959
Typic Haplustept	6.00 x10^{-9} exp (13.006 θ)	0.991	2.00 x10^{-13} exp (13.064 θ)	0.990
Vertic Haplustept	3.00 x10^{-9} exp (13.705 θ)	0.937	1.00 x10^{-15} exp (13.705 θ)	0.937
Ultic Paleustalf	1.00 x10^{-7} exp (11.633 θ)	0.947	6.00 x10^{-13} exp (13.054 θ)	0.929
Typic Paleustalf	7.00 x10^{-8} exp (9.702 θ)	0.977	2.00 x10-^{13} exp (13.597 θ)	0.934
Rhodic Paleustalf	3.00 x10^{-8} exp (12.194 θ)	0.893	2.00 x10-^{12} exp (13.000 θ)	0.929
Typic Rhodustalf	2.00 x10^{-8} exp (10.749 θ)	0.964	4.00 x10^{-14}exp (14.067 θ)	0.930
Typic Ochraqualf	1.00 x10^{-9} exp (14.135 θ)	0.928	2.00 x10^{-15}exp (14.698 θ)	0.935
Aeric Ochraqualf	5.00 x10^{-9} exp (13.148 θ)	0.897	1.00 x10^{-12}exp (12.774 θ)	0.812
Typic Haplustalf	4.00 x10^{-9} exp (13.245 θ)	0.952	1.00 x10^{-13}exp (12.712 θ)	0.944
Kandic Paleustalf	6.00 x10^{-9} exp (13.044 θ)	0.926	1.00 x10^{-14}exp (14.424 θ)	0.909
Aeric Fluvaquent	7.00 x10^{-10} exp (4.508 θ)	0.852	1.00 x10^{-13} exp (5.719 θ)	0.837
Typic Ustipamment	6.00 x10^{-8} exp (16.872 θ)	0.920	2.00 x10^{-12}exp (17.742 θ)	0.907
Typic Ustorthent	1.00 x10^{-8} exp (12.076 θ)	0.906	7.00 x10^{-13}exp (11.477 θ)	0.904
Lithic Ustorthent	1.00 x10^{-9} exp (12.876 θ)	0.959	1.00 x10^{-14}exp (12.943 θ)	0.937
Typic Chromustert	9.00 x10^{-10} exp (13.253 θ)	0.891	4.00 x10^{-15}exp (12.931 θ)	0.882
Chromic Haplustert	4.00 x10^{-10} exp (11.811 θ)	0.932	8.00 x10^{-16}exp (11.811 θ)	0.932
Typic Haplustert	4.00 x10^{-10}exp (15.387 θ)	0.947	6.00 x10^{-16} exp (15.387 θ)	0.947
Lithic Haplustoll	4.00 x10^{-9} exp (4.771 θ)	0.880	2.00 x10^{-14}exp (4.771 θ)	0.88

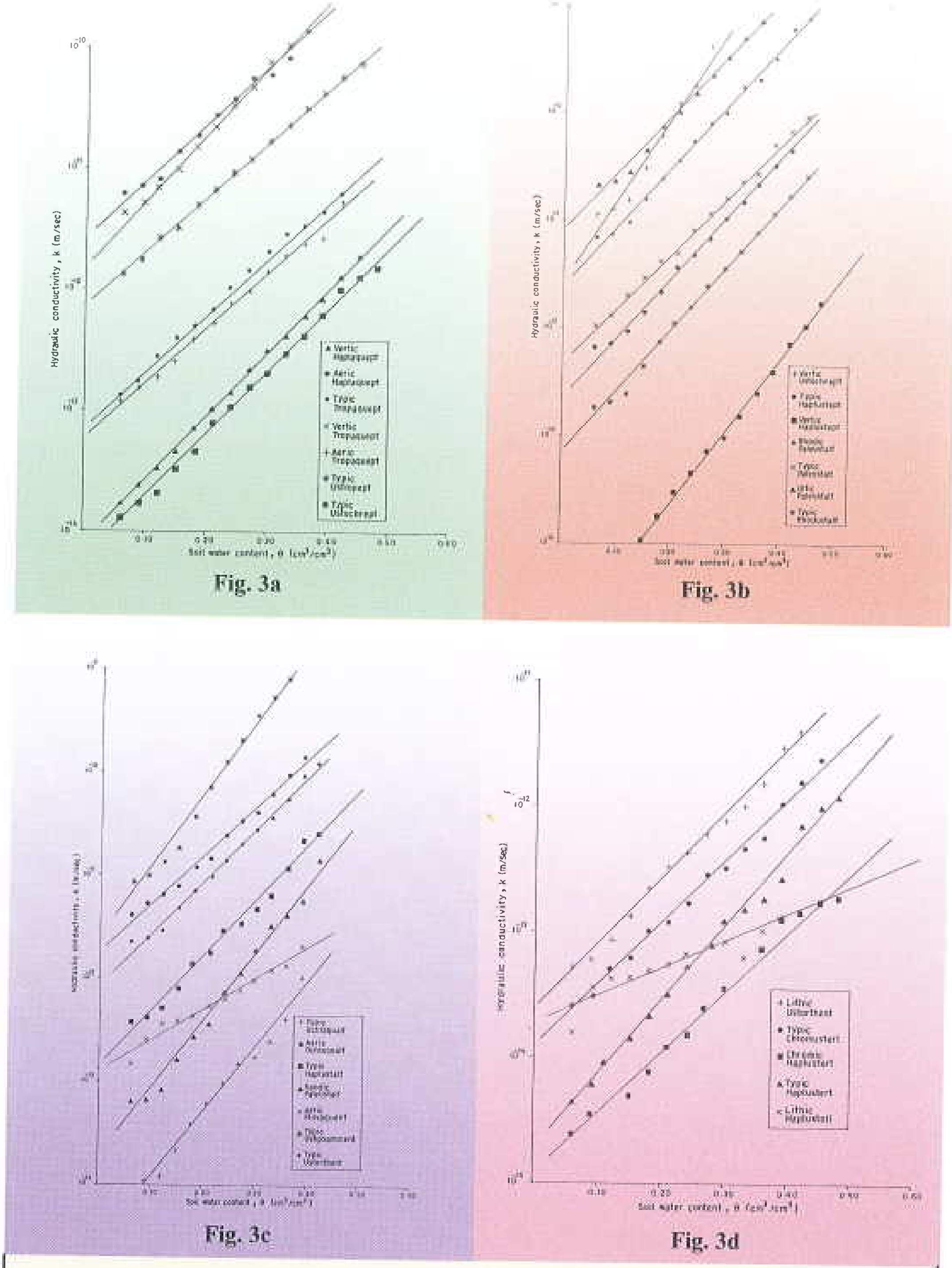


Fig. 3a

Fig. 3b

Fig. 3c

Fig. 3d

Fig. 3a,b,c,d Hydraulic conductivity as a function of water content

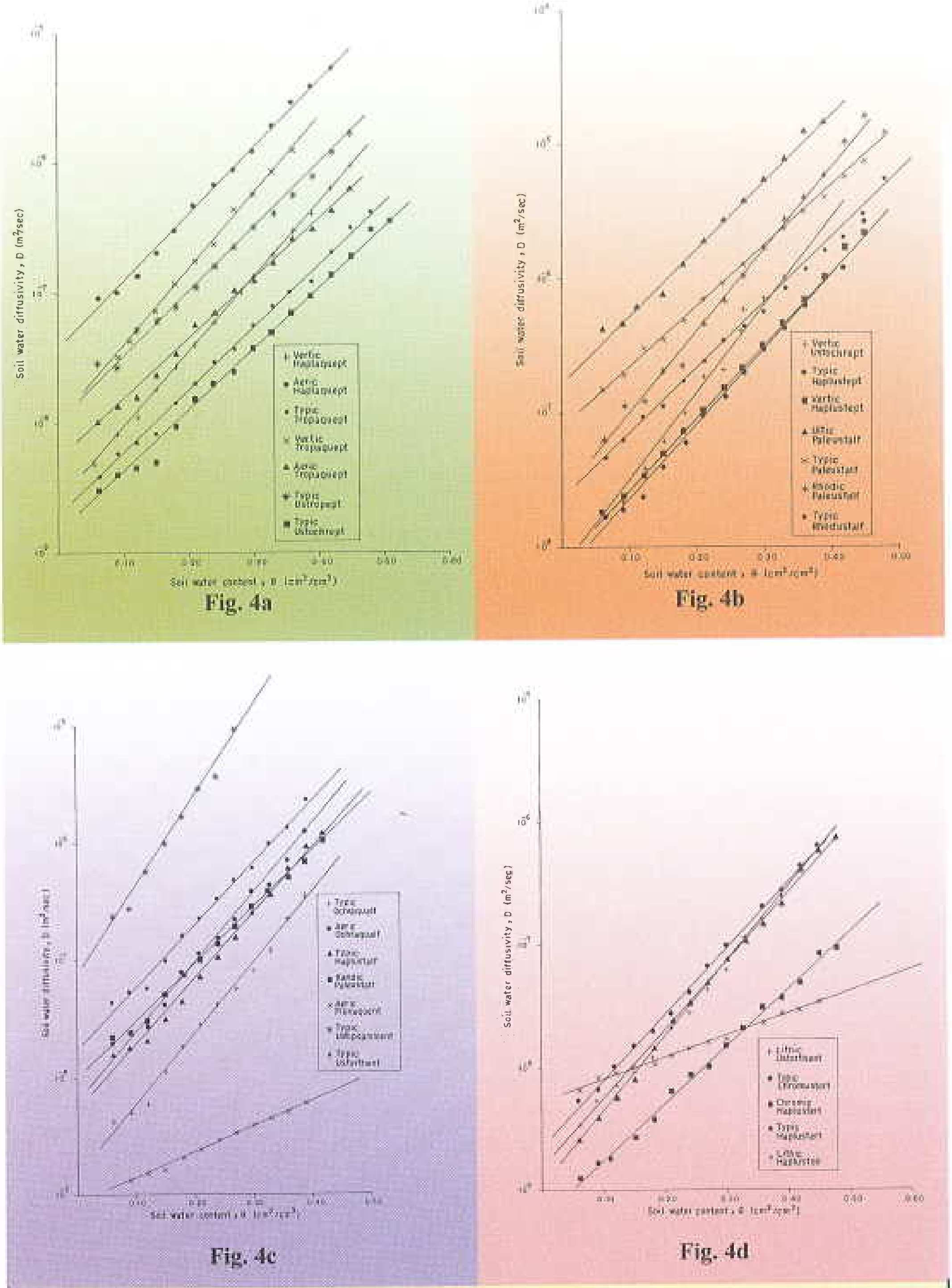


Fig. 4a

Fig. 4b

Fig. 4c

Fig. 4d

Fig. 4a,b,c,d Soil water diffusivity as a function of water content

5. Scaling of Soil Hydraulic Properties

Two pre-requisites for scaling of any soil hydraulic function are (i) for a given water content, x versus $t^{1/2}$ plot is linear, and (ii) the hydraulic function and water content relation is of same form for all the soils, differing only by a constant factor (Reichardt *et al.* 1972). Relationship between the distance of wetting front from the inlet end of soil columns (Xwf) and sqare root of time for infiltration into horizontal soil column ($t^{1/2}$) are shown in Fig.5. Data point for each of the 26 soil subgroups clustered around a straight line passing through the origin, thereby fulfilling the first condition for scaling any soil hydraulic function.

To calculate characteristics length, λ_i for the subgroups, Vertic Tropaquept was arbitrarily taken as the reference soil for which the value of λ was taken as unity. The values of λ for other soils presented in Table 17 were calculated from equation 12. Using experimentally measured water content in the profiles, water diffusivity was calculated for all the 26 soil subgroups. All the studied soils showed exponential behaviour of soil water diffusivity and conductivity with profile moisture content [$D(\theta) = D_0 \exp(\beta\theta)$ and $K(\theta) = K_0 \exp(\beta^0\theta)$]. The values of D_0, β, K_0, β^0 are presented in Table 4. Diffusivity, $D(\theta)$ and conductivity $K(\theta)$ increased exponentially with increase in θ for all the twenty six soils. Both the conditions as pointed out by Reichardt *et al.* (1972) for scaling hydraulic functions were fulfilled by the twenty six soils. The relationship between scaled soil water diffusivity $D^*(\Theta)$ and dimension less moisture content (Θ) for all the subgroups was described by the following equation with regression coefficient of 0.893.

$$D^*(\Theta) = 9.0 \text{ x } 10^{-11} \exp(6.032\ \Theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Combining equations 8 and 12, an equation was obtained for calculation of the soil water diffusivity in a given soil i, as a function of m_i,

$$D_i(\theta) = \lambda_s \gamma m_i^2 / \eta m_s^2 . D^*(\Theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

Using expression 19 for $D^*(\Theta)$ and putting values of all the constants, equation 20 reduces to:

$$D_i(\theta) = 1.565 \text{ x } 10^{-2} m_i^2 \exp(6.032\ \Theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

where $D_i(\theta)$ is given in m^2s^{-1}

The relationship between scaled soil water conductivity $K^*(\Theta)$ and dimension less moisture content (Θ) for all the subgroups was described by the following equation with regression coefficient of 0.192.

$K^* (\Theta) = 9.0 \times 10^{-21} \exp (4.885\ \Theta)$ …… ………………………………… (22)

Combining equations 9 and 12, an equation was obtained for calculation of the hydraulic conductivity in a given soil i, as a function of m_i,

$K_i (\theta) = \rho g \lambda_s m_i^4 / \eta m_s^4 . K^* (\Theta)$ ……………………………………… ….. (23)

Using expression 22 for K* (Θ) and putting values of all the constants, equation 23 reduces to:

$K_i (\theta) = 4.219 \times 10^{-1}\ mi^4 \exp (4.885\ \Theta)$ …………………… …….(24)

where $D_i (\theta)$ is given in ms^{-1}

The regression coefficient for hydraulic conductivity function is very low hence scaling of hydraulic conductivity function is not very reliable.

The relationship between scaled soil water conductivity h* (Θ) and dimension less moisture content (Θ) for all the subgroups was described by the following equation with regression coefficient of 0.875.

$h^* (\Theta) = 5.924 \times 10^4\ \Theta^{-4.611}$ ……………………………………… (25)

An equation for calculation of pressure head was obtained by combining equations 10 and 12:

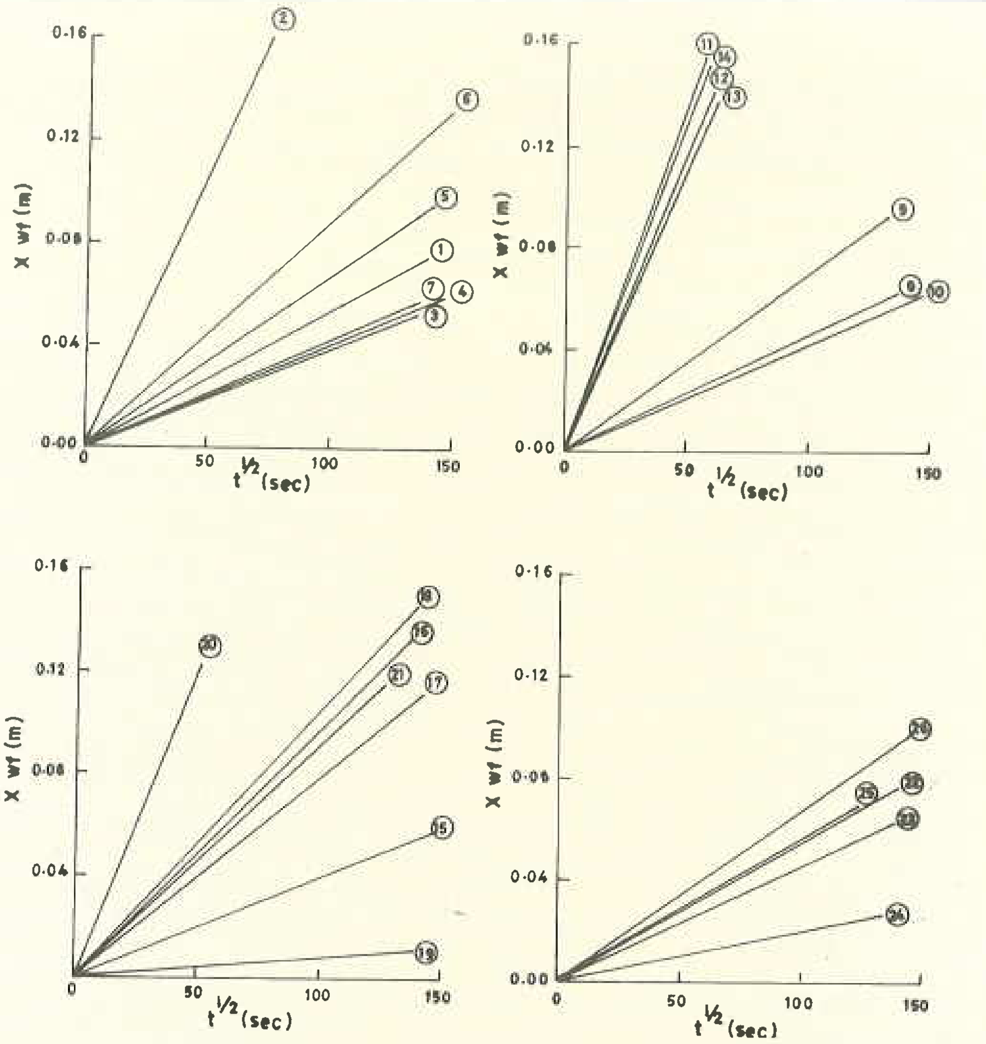
$h_i (\theta) = \gamma m_s^2 / \lambda_s \rho g m_i^2 . h^* (\Theta)$ … ………… ……… … ………………(26)

Using expression 25 for h* (Θ) and after substituting the values of constants, equation 26 reduces to:

$h_i (\theta) = 2.197 \times 10\text{-}7\ m_i^2 (\Theta)^{-4.611}$ …………………………………… (27)

where 'h_i' is given in m. Thus to estimate soil water diffusivity and pressure head of any soil 'i', a horizontal infiltration run has to be made to determine its 'm_i'.

The scaling technique can be suitably used for evaluating hydraulic functions under field situations, by resorting to sampling from each soil horizon and packing the soil to bulk densities as close as possible to the field condition. In field situation where soil heterogeneity is pronounced, the scaling technique can successfully predict movement, retention and use of water. These findings are applicable to all dominating soil subgroups occurring over vast areas in eastern region of the country. Such equation developed for a region can be used for quick and reliable estimation of water diffusivity or moisture retention characteristics of any soil there.



Sl. No	Name of Soil group	Sl. No	Name of Soil group	Sl. No	Name of Soil group
1.	AericTropaquept	10.	Vertic Haplustept	19.	Aeric Fluvaquent
2.	Aeric Haplaquept	11.	Ultic Paleustalf	20.	Typic Ustipamment
3.	Typic Ustochrept	12.	Typic Paleustalf	21.	Typic Ustorthent
4.	Vertic Haplaquept	13.	Rhodic Paleustalf	22.	Lithic Ustorthent
5.	Vertic Tropaquept	14.	Typic Rhodustalf	23.	Typic Chromustert
6.	Typic Ustropept	15.	Typic Ochraqualf	24.	Chromic Haplustert
7.	Typic Tropaquept	16.	Aeric Ochraqualf	25.	Typic Haplustert
8.	Vertic Ustochrept	17.	Typic Haplustalf	26.	Lithic Haplustoll
9.	Typic Haplustept	18.	Kandic Paleustalf		

Fig.5 Position of wetting point (x wf) as a function of square root of time for horizontal infiltration

Table 17. Values of some important measured and calculated parameters of the studied soils

Name of the soil subgroup	m ($ms^{-1/2}$)	λ
AericTropaquept	5.300×10^{-4}	0.55
Aeric Haplaquept	2.146×10^{-3}	9.01
Typic Ustochrept	4.140×10^{-4}	0.33
Vertic Haplaquept	4.320×10^{-4}	0.36
Vertic Tropaquept	7.150×10^{-4}	1.00
Typic Ustropept	9.170×10^{-4}	1.64
Typic Tropaquept	3.760×10^{-4}	0.28
Vertic Ustochrept	4.530×10^{-4}	0.40
Typic Haplustept	7.260×10^{-4}	1.03
Vertic Haplustept	4.350×10^{-4}	0.37
Ultic Paleustalf	2.575×10^{-3}	12.97
Typic Paleustalf	2.429×10^{-3}	11.54
Rhodic Paleustalf	2.355×10^{-3}	10.85
Typic Rhodustalf	2.804×10^{-3}	15.38
Typic Ochraqualf	3.980×10^{-4}	0.31
Aeric Ochraqualf	9.660×10^{-4}	1.83
Typic Haplustalf	8.000×10^{-4}	1.25
Kandic Paleustalf	1.043×10^{-3}	2.13
Aeric Fluvaquent	7.390×10^{-5}	0.01
Typic Ustipamment	2.440×10^{-3}	11.65
Typic Ustorthent	9.430×10^{-4}	1.74
Lithic Ustorthent	5.650×10^{-4}	0.62
Typic Chromustert	4.710×10^{-4}	0.43
Chromic Haplustert	2.470×10^{-4}	0.12
Typic Haplustert	5.260×10^{-4}	0.54
Lithic Haplustoll	7.010×10^{-4}	0.96

6. Water Management Strategies

I. Strategies for soils with high to very high profile water storage capacity:

- Soils belonging to Vertic Haplaquept, Typic Tropaquept, AericTropaquept, Typic Ustochrept, vertic Haplustept, Typic Haplustalf, Lithic Ustorthent, Aeric Fluvaquent and Typic Haplustert subgroups have very high profile water storage capacity. Soils belonging to Aeric Haplaquept, Typic Ustropept, Typic Ochraqualf, Aeric Ochraqualf, Typic Ustorthent, Typic Chromustert and Lithic Haplustoll subgroups have high to very high profile water storage capacity. Medium to heavy irrigation applied at long intervals will be effective for higher water use efficiency and crop yields in these soils. In such soils with very high profile water storage capacity, cultivation of a second crop like green gram, blackgram and horse gram without irrigation is possible after rainy season provided these crops are sown soon after the harvest of *kharif* rice by the end of November. These soils can support crop production for a longer period.

II. Strategies for soils with medium to high profile water storage capacity:

- Soils belonging to Typic Haplustept, Typic Paleustalf and Chromic Haplustert subgroups show high, soils of Vertic Ustochrept, Kandic Paleustalf and Typic Rhodustalf subgroups show medium to high, and soils of Ultic Paleustalf and Rhodic Paleustalf subgroups show medium profile water storage capacity. In these soils, a life-saving irrigation will be required for raising such a pulse or an oilseed crop like sesamum after the harvest of *kharif* rice. Frequent and light irrigation in check basins, border strip or furrows at optimum irrigation schedule may prove to be highly effective in improving water-use efficiency of different crops in these soils.

III. Strategies for soils with low to medium profile water storage capacity:

- Soils of Vertic Tropaquept subgroup exihibit low to medium and Typic Ustipsamment show low profile water storage capacity. Cultivation of a second crop after harvest of *kharif* rice is not possible in these soils without irrigation. Frequent and light irrigation, preferably by drip and sprinkler system will prove useful to improve water use efficiency and increase crop yield in such soils. Use of green manures and FYM is a must for enhancing crop yields and maintaining soil health.

IV. Strategies for soils with poor water transmission property:

- Soils of Aeric Fluvaquent subgroup showed highest moisture retentivity and available water capacity but lowest water transmission characteristics i.e, penetrability, intrinsic penetrability, sorptivity, weighted mean diffusivity, intrinsic weighted mean diffusivity. Although this soil subgroup has high available water capacity, they are unable to supply sufficient water to plants because of their low transmission characteristics. It may be due to their high salt content. Frequent supply of water to lower the suction is required for successful crop production in these soils. Proper selection of crops and monitoring of salt content in such soils are very important.

- Soils belonging to Typic Chromustert, Chromic Haplustert and Typic Haplustert subgroups are clay in texture with tremendous swell-shrink potential and high bulk density. Despite high to very high profile water storage capacity, these soils are poor in water transmission characteristics. Soils of these subgroups exihibit medium to very high erosion index. Adoption of suitable management practices for *in situ* conservation of soil and water will be necessary to improve water use efficiency and crop production in these sub groups. These soils need to be ploughed at proper tilth. Since these soils are poor in water transmission characteristics, plants suffer from drought even at moderate soil moisture status. Application of organic materials like rice straw, sawdust, molasses, etc. would improve soil aggregability and water movement in these soils. Medium to heavy irrigation applied at long intervals will be effective. Problem of waterlogging is more in these soils, hence proper drainage is essential.

V. Strategies for soils of high erodibility and light-textured soils:

- General trend of dispersion and erosion reveals that the soils belonging Entisols and Inceptisols subgroups are highly prone to soil and water erosion, and soil and water conservation measures need to be taken on priority basis in these areas. Drip, sprinkler, basin and furrow irrigation methods are recommended for highly erodible soils.

- Acid soils or soil acidity of the eastern region pose typical soil and water management problems, which are mostly associated with physical and chemical properties of soils. Kaolinite dominated light textured acid soils have very high saturated hydraulic conductivity leading to heavy percolation losses. This can be controlled by compaction. Light and frequent irrigation help in enhancing water and nutrient-use efficiency on these soils. Problems of high evaporative demands on crusting soils can be managed by mulching the croplands with available paddy straw. Mulching not only lowers evapotranspiration of the crops but also saves irrigation water to the tune of 15-20 % in different crops. Hardening of red loamy soils can be avoided by incorporating paddy husk and powdered groundnut shells into soils followed by light irrigation. This technique helps in enhancing moisture recharging in the profile and carry-over enough moisture for subsequent *rabi* crops. 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.

- Application of FYM @ 10t/ha has been observed to be most effective for enhancing productivity and maintaining good physical characteristics and soil health of these soils
- Sesbania green manuring @ 40 kg seed/ha proved to be highly beneficial in increasing the productivity of *rabi* crops in rice based cropping system and cut-down nitrogen requirement by 30-40%.

VI. Strategies for optimum use of residual soil moisture:

- Advanced sowing of *kharif* crops and adoption of early and medium duration varieties of rice can ensure successful *rabi* cultivation on residual moisture without any irrigation in high to very high profile moisture storage capacity soils. This practice can increase the cropping intensity of the region. Mulching and paira cropping are the othe feasible alternatives for enhancing cropping intensity.
- Use of locally available mulch materials like rice straw etc. for reducing evapotranspiration loss of profile water can improve water-use efficiency of different crops.
- Zero tillage, *paira* cropping and mulching during *rabi* season are effective alternatives to raise crops on residual soil moisture.

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