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Water Retention Characteristics of Various Soil Types under Diverse Rainfed Production Systems of India

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ABSTRACT: The relationships of soil water retention at 1/3 and 15 bar and available water content with soil physicochemical properties were studied in 147 soil samples collected from 21 profiles from rainfed regions of the country. In general Vertisols and Vertic sub-groups showed higher water retention at 1/3 and 15 bars, and available water content. A number of profiles showed an increasing trend in water retention with increase in soil depth. Reduction in water retention from 1/3 bar to 15 bar was greater in Inceptisols/Entisols, Alfisols/Oxisols and Aridisols than in Vertisols. Amount of clay and CEC showed significant positive correlation, while sand showed negative correlation with soil water retention. The relationships between organic carbon and water retention in surface soils were non-significant. Multiple regression analysis for pooled soils (n=147) showed that EC, $CaCO_3$, sand, clay and CEC contributed to the variations in available water in soil.

Keywords: Water retention; soil types; physico-chemical properties; rainfed soils

Water retention capacity of soils is of primary importance in plant growth and successful crop production. In India, ⅔ of total cultivated land is rainfed and depends mostly on southwest and northeast monsoon, both for surface and groundwater resources. Rainfed regions make a major contribution to pulses, oilseed and millet production. However low and erratic rainfall and degraded lands of these regions often limit crop productivity. Hence, rainwater conservation and its efficient utilization at critical stages of crop growth, is crucial for successful rainfed agriculture (Singh *et al.,* 2004). In this context, the amount of water that can be retained in soil profile is most critical, especially between dry spells. However, the amount of water retained in a particular soil and its subsequent availability to crop plants depends upon type of soil, texture, nature of minerals and other soil properties. Therefore understanding the water retention characteristics of soil types of rainfed regions is important for efficient rainwater conservation and for its optimum usage for practical soil water management (Eswaran *et al.,* 1988). Some studies were carried out earlier on soils of Andhra Pradesh (Srinivasarao et al., 1990; Prasad *et al.,* 1998), Uttar Pradesh (Bhatnagar et al., 1999), Rajasthan (Singh *et al.,* 2001) and Maharashtra (Mandal *et al.,* 2003). However, systematic studies on water storage capacity of soils of rainfed regions are lacking. Hence, a comprehensive study was undertaken to examine the water retention characteristics of different soil types in rainfed regions of India.

Materials and Methods

Samples of soils from 21 rainfed locations, (each with 7 depths, 15 cm interval) were collected from 8 diverse rainfed production systems, processed and used for analysis. Pressure plate apparatus was used to determine water retention at 1/3 bar and 15 bars and the difference between these two was taken as the available water content (Richards, 1965). The Bouyoucos hydrometer method was followed for the estimation of particle size distribution. Soil pH and EC (1:2.5, soil:water) were measured using glass electrode and EC-TDS analyzer respectively. The organic carbon content was determined by rapid titration method of Walkley and Black (1934). CEC was determined following the method described by Jackson (1973). Correlation between retention characteristics and soil properties were worked out as per Gomez and Gomez (1984).

Results and Discussion

Details of soils

Inceptisols are located mainly in Indo-Gangetic plains covering states of Punjab, Uttar Pradesh and Jammu and Kashmir and support variety of crops like upland rice, pearmillet, maize and sorghum based systems. Most of these soils are deep Inceptisols with semi-arid and sub-humid climate. Mean annual rainfall exceeds 1000 mm except at Agra where mean annual rainfall is 665 mm and accordingly length of growing season varies between 90-120 days. Alfisols and Oxisols occur in southern and eastern India supporting upland rice, groundnut and fingermillet based systems and depth varying from shallow to deep. Climate of these regions varies from arid to sub-humid with mean annual rainfall ranging from 590 to 1378 mm and length of growing period from 90 – 210 days. Vertisols and associated soils are located in southern plateau and western regions of the country with arid, semi-arid and sub- humid climate and shallow to deep in depth. Mean annual rainfall ranges from 500 to 944 mm with length of growing season being 60-150 days. Vertisols and associated soils support a variety of production systems like groundnut, soybean, cotton, rabi sorghum and maize. Aridisols are located in western region of the country supporting pearlmillet based production systems with arid climate, deep alluvial to desert soils, mean annual rainfall ranging from 400 – 500 mm and length of growing season between 60- 90 days.

Soil properties

Among Vertisols/Vertic sub-groups all the soils except of Arjia showed clay content above 50% (Table 1) and the highest clay contents were observed in Solapur profile ranging from 74.7 to 75.6%. In Arjia profile it varied from 13.1% in lower depth (90–105 cm) to 33.1% (0–15 cm). Most of the profiles, except Rajkot and Arjia showed increasing trend of clay with depth. Organic carbon content decreased with depth and its content was low in most of the profiles. CEC varied widely among Vertisols and Rewa profile showed the lowest CEC around 20 c mol (p^{+}) kg^{-1} while all other profiles showed relatively higher levels. In Alfisols/Oxisols, clay and CEC contents increased with depth. Except Ranchi (0.62%) remaining 3 profiles were low in organic carbon. Among Inceptisols/Entisols, higher clay content was observed in Jhansi between 36 to 47% while the lowest was found in Rakh-Dhiansar ranging from 12 to 18%. Under Aridisols, Hisar profile had fine texture compared to SK Nagar. Many Vertisols and Vertic sub groups and some Inceptisols showed higher contents of $CaCO_3$ while Alfisols/Oxisols and Aridisols were non-calcareous.

Water retention characteristics

Profile mean water availability of all the 21 locations is presented in Table 1. Water retention at 1/3 bar (field capacity) showed that among Vertisols and associated soils, except Arjia (ranged from 2.2 to 11.2%), all other soils showed higher retention above 30% (Fig. 1a). All the four Alfisols/Oxisols showed more or less similar levels of water retention in deeper layers though there were differences in surface layer. Among Alfisols/Oxisols, in surface layer, lowest water retention was found in Bangalore profile (9.1%), while the highest water retention was observed in Anantapur profile (14.9%). Wide variation in water retention at 1/3 bar was observed in Inceptisols/Entisols. Soils of Rakh-Dhiansar profile showed very low level of water retention (from 4 to 7%), while the highest was found in Faizabad profile (from 23 to 26%). Among Aridisols, SK Nagar profile showed very low retention, ranging from 2 to 5%, while Hisar profile showed between 10 to 22%. Most of the profiles showed increasing trend in water retention at 1/3 bar with increasing soil depth.

At 15 bar (permanent wilting point) water retention levels drastically reduced from retention levels at 1/3 bar in Alfisols/Oxisols, Inceptisols/Entisols and Aridisols while in Vertisols and associated soils the reduction was relatively less. In general, trend in water retention at 15 bar was similar to that of 1/3 bar (Fig. 1b). Such reductions in water retention with increasingly pressure on some Inceptisols of Assam were reported at Patgiri and Baruah (1996). Vertisols of Arjia, Inceptisols/Entisols of Agra, Hoshiarpur, Rakh-Dhiansar, Jhansi and Aridisols of SK Nagar showed very low retention at 15 bar.

Available water (difference between 1/3 bar and 15 bar) levels were in general higher (5.5 to 18.8%) in Vertisols except Arjia followed by Inceptisols/Entisols, Alfisols/Oxisols and Aridisols (Fig. 1a-1c). In Vertisols,

Table 1. Properties and water retention (% wt. basis) characteristics of 21 dryland soils (Mean of 7 layers of the profies)

Location / Production system	pH	EC (dSm^{-1})	$CaCO_3$ (%)	OC (%)	Sand (%)	Silt (%)	Clay (%)	CEC (cmol (p+) kg^{-1})	Water retained at (bar) 1/3 (%)	15 (%)	Available (%)
Vertisols/Vertic sub groups											
Rajkot (Groundnut-based production system)	8.1	0.10	8.46	0.38	26.5	12.1	61.3	28.5	35.1	23.5	11.6
Indore (Soybean-based production system)	7.9	0.24	4.65	0.61	7.6	29.9	62.5	53.6	33.0	19.9	13.1
Rewa (Soybean-based production system)	7.5	0.10	0.78	0.17	28.0	23.1	48.8	21.4	29.6	16.0	13.6
Akola (Cotton-based production system)	8.3	0.13	19.03	0.18	18.9	19.1	62.0	60.5	36.8	25.3	11.5
Kovilpatti (Cotton-based production system)	8.0	0.80	11.26	0.36	29.8	5.9	64.3	53.7	40.4	26.7	13.8
Bellary (Rabi-Sorghum based production system)	8.7	0.33	15.84	0.22	20.4	13.1	66.5	29.2	35.8	23.0	12.8
Bijapur (Rabi-Sorghum based production system)	8.6	1.40	19.93	0.27	20.4	17.7	61.9	33.9	45.7	24.7	21.0
Solapur (Rabi-Sorghum based production system)	8.1	0.12	5.37	0.30	11.5	13.6	74.9	39.5	42.6	30.5	12.1
Arjia (Maize-based production system)	8.3	0.14	3.39	0.24	63.6	13.1	23.2	18.7	6.6	2.5	4.0
Alfisols/Oxisols											
Phulbani (Rice-based production system)	6.0	0.03	0.38	0.12	55.5	11.1	33.4	13.2	18.2	9.8	8.4
Ranchi (Rice-based production system)	6.9	0.05	1.09	0.28	43.5	18.4	38.1	28.7	15.8	10.9	4.9
Anantapur (Groundnut-based production system)	6.8	0.09	3.20	0.17	60.5	9.1	30.3	13.0	18.3	8.3	10.0
Bangalore (Finger millet-based production system)	5.8	0.07	0.93	0.16	57.6	3.3	39.3	11.8	14.1	8.6	5.5
Inceptisols/Entisols											
Faizabad (Rice-based production system)	8.1	0.29	1.11	0.18	28.6	32.0	39.3	25.9	24.6	10.4	14.2
Agra (Pearl millet- based production system)	8.8	0.69	1.59	0.19	45.6	17.4	37.0	25.2	21.1	8.4	13.0
Hoshiarpur (Maize-based production system)	7.9	0.14	3.94	0.37	72.2	14.3	16.8	9.5	9.3	4.1	5.2
Rakh Dhiansar (Maize-based production system)	7.2	0.04	2.43	0.38	79.5	7.1	14.0	6.4	5.1	2.0	3.0
Jhansi (Maize-based production system)	7.3	0.22	7.51	0.38	39.5	15.7	44.8	30.3	20.3	3.8	16.4
Varanasi (Maize-based production system)	7.2	0.13	6.03	0.21	39.2	17.7	42.2	29.3	21.1	7.5	13.6
Aridisols											
Hisar (Pearl millet-based production system)	7.4	1.79	0.91	0.15	55.9	17.5	26.6	18.2	15.9	5.7	10.3
S.K Nagar (Pearl millet-based production system)	8.0	0.04	1.09	0.43	84.1	4.1	11.7	8.4	3.1	1.7	1.4

Arjia profile showed available water between 2 to 7% (lowest), while in the Bijapur profile it ranged from 15 to 28% (highest). Similarly, in Alfisols/Oxisols Ranchi profile showed the range of 4 to 5%, while Anantapur profile showed in between 9 to 12%. Among Inceptisols/ Entisols, Rakh-Dhiansar profile showed water retention in the range of 1 to 4% while the Faizabad soils it was between 11 to 20%. In Aridisols of SK Nagar water retention ranged from 1 to 3%, while it ranged in Hisar profile from 7 to 13%. Challa and Gaikwad (1987) stated that available water was generally higher in Vertisols and Vertic intergrades and was more uniformly distributed in the profile when compared to Entisols. Anil *et al.* (1999) reported that moisture stress during different growth stages of sorghum was related to parent material and the stress was more in sandstone than in basaltic soils.

In general, water retention characteristics of various soil types were related to clay content. Vertisols and associated soils, with high clay content showed, higher water retention. Clay content showed highly significant positive correlation with water retention parameters in all the soil types (Table 2). Similarly, most of the soil types showed highly significant positive correlation with CEC, except in Vertisols. This could be due to dominant effect of clay/texture/swell-shrink type on water retention in soils from heterogeneous soil types and also from different depths. Ali and Biswas (1971) observed that at low matric suction, moisture was retained in the internal and external surface of clay, while at higher matric suction, the moisture was retained only on the external surface of clay. In most of the profiles, clay content increased with depth, which had a significant effect on water retention, while organic carbon content decreased with depth. Such negative correlations were obtained in some soil types. However, relationship between organic carbon and water retention parameters was positive but non-significant for surface layer samples (0–15 cm). Rawls *et al.* (2003) reported the positive relationship between organic carbon and soil water retention in sandy soils while it was negative in fine textured soils. Soil pH had positive relation with water retention in Vertisols, Alfisols/ Oxisols and Inceptisols/Entisols while in Aridisols it was significantly negative. EC had positive correlation in all the soil types while in association of $CaCO_3$ and water retention varied between negative to positive among soil types. Sand content showed a negative correlation with water retention in most of the soil types. Similar, observations were made earlier by Prasad *et al.* (1998) for different soil types of Andhra Pradesh.

Multiple regression equations indicating the extent of variation contributed by the soil properties to water retention characteristics are presented in table 3. In Aridisols, $CaCO_3$, OC and clay contributed higher in available water content of soils. Soil pH, OC, sand, clay and CEC contributed higher in Alfisols while in Vertisols pH, EC, $CaCO_3$, OC, sand and CEC contributed significantly. In case of Inceptisols the variations in available water content are largely determined in pH, EC, $CaCO_3$, OC, sand, silt, clay and CEC. Overall, based on pooled samples (n=147), EC, $CaCO_3$, sand, clay and CEC contributed significantly to the variation in available water content.

These results show that wide variation exists in water retention characteristics not only among soil types but also within each soil type. As different production systems are practiced on each soil type, water management practices would differ depending upon water retention and production systems. These retention characteristics along with soil depth determine the length of cropping season and management of crops during drought period.

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Table 2. Correlation coefficients between soil properties and water retention characteristics

Soil type/group	Soil properties	Water retained at		
		1/3 bar	15 bar	Available water
Vertisols/Vertic sub groups (n=63)	pH	0.08[ns]	0.06[ns]	0.10[ns]
	EC	0.41**	0.27*	0.57**
	$CaCO_3$	0.42**	0.37**	0.40**
	sand	-0.79**	-0.77**	-0.63**
	silt	0.04[ns]	-0.07[ns]	0.22[ns]
	clay	0.87**	0.90**	0.60**
	CEC	0.49**	0.55**	0.24[ns]
Alfisols/Oxisols (n=28)	pH	0.54**	0.54**	0.20[ns]
	EC	0.05[ns]	-0.21[ns]	0.30[ns]
	$CaCO_3$	0.32[ns]	-0.06[ns]	0.53**
	sand	-0.49**	-0.89**	0.25[ns]
	silt	0.16[ns]	0.36[ns]	-0.16[ns]
	clay	0.48**	0.82**	-0.20[ns]
	CEC	0.20[ns]	0.66**	-0.42*
Inceptisols/Entisols (n=42)	pH	0.38*	0.55**	0.16[ns]
	EC	0.51**	0.56**	0.34*
	$CaCO_3$	0.07[ns]	-0.31*	0.30*
	sand	-0.96**	-0.73**	-0.87**
	silt	0.78**	0.72**	0.62**
	clay	0.89**	0.61**	0.84**
	CEC	0.75**	0.55**	0.69**
Aridisols (n=12)	pH	-0.92**	-0.93**	-0.89**
	EC	0.85*	0.94**	0.78**
	$CaCO_3$	-0.08[ns]	0.11[ns]	-0.17[ns]
	sand	-0.99**	-0.96**	-0.98**
	silt	0.98**	0.94**	0.97**
	clay	0.99**	0.96**	0.98**
	CEC	0.99**	0.98**	0.96**

* Significant at 5 % level of significance

**Significant at 1 % level of significance

ns-non significant

Fig. 1a. Water retention by different soil types at 1/3 bar

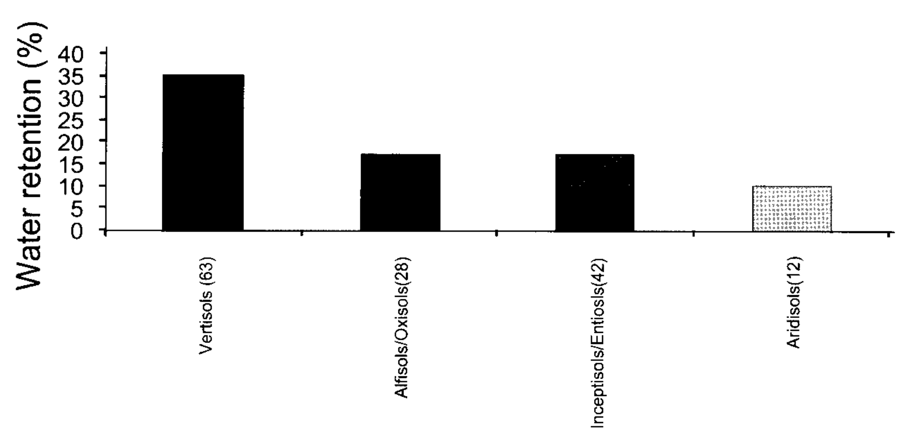

Fig. 1b. Water retention by different soil types at 15 bar

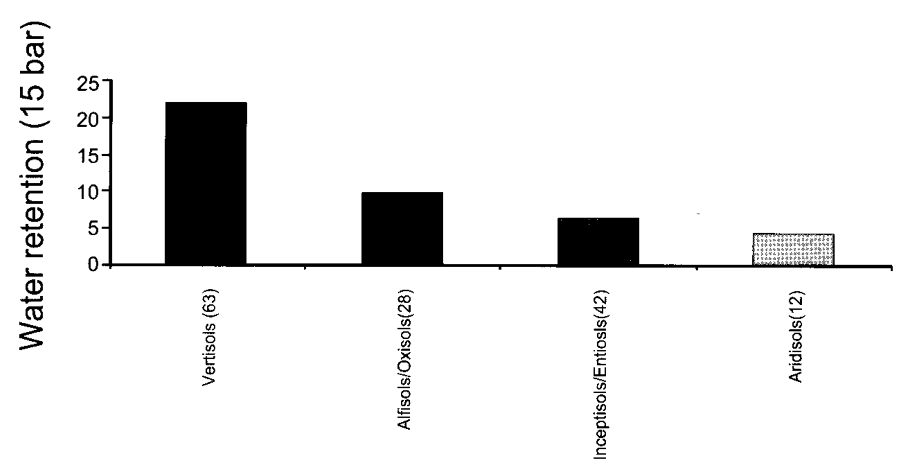

Fig. 1c. Available water content in different soil types under rainfed production systems

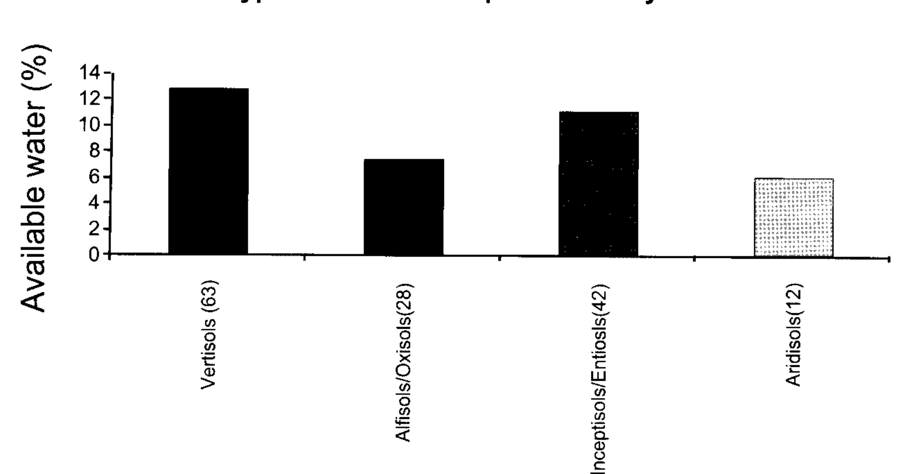

Table 3. Multiple regression equations between water retention and soil properties of rainfed soils

Soil type/water retention at	Multiple regression equation	R^2
Aridisols (n=14)		
15 bar	-0.8 + 0.61 EC + 0.30 CEC	0.99
1/3 bar	-5.71 – 2.29 OC + 0.83 Clay	0.99
Available water	-2.71 – 1.31 $CaCO_3$ – 1.86 OC + 0.54 clay	0.98
Alfisols (n =28)		
15 bar	25.13 – 36.2 EC + 0.72 $CaCO_3$ –0.24 Sand – 0.14 Silt	0.85
1/3 bar	26.56 – 60.8 EC + 1.90 $CaCO_3$ – 15.98 OC – 0.11 sand	0.68
Available water	23.43 + 2.35 pH – 9.01 OC – 0.26 sand – 0.27 clay – 0.36 CEC	0.69
Vertisols (n =63)		
15 bar	44.35 + 1.59 EC – 0.53 sand – 0.62 silt	0.82
1/3 bar	60.46 + 5.22 EC – 0.69 sand –0.66 silt	0.81
Available water	53.7 – 4.74 pH + 3.34 EC + 0.43 $CaCO_3$ + 6.49 OC – 0.16 sand – 0.14 CEC	0.70
Inceptisols (n =42)		
15 bar	23.39 + 2.94 EC – 12.4 OC – 0.17 sand – 0.16 clay	0.80
1/3 bar	20.88 + 1.81 pH + 0.35 sand	0.80
Available water	3.5 + 1.18 pH + 0.84 EC +0.32 $CaCO_3$ + 10.89 OC – 0.19 sand + 0.025 silt + 0.082 clay + 0.0095 CEC	0.80
Pooled (n=147)		
15 bar	23.18 + 0.96 pH + 0.109 sand + 0.5 clay	0.83
1/3 bar	7.56 + 2.76 EC + 0.24 $CaCO_3$- 0.13 sand + 0.44 clay	0.88
Available water	26.49 + 1.79 EC + 0.21 $CaCO_3$ – 0.26 sand – 0.10 clay – 0.08 CEC	0.65

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