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Soil moisture characteristics under varying physiographic and land use situation

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ABSTRACT

Efficient use of water resources for optimization of crop productivity and proper land and water management both under irrigated and rainfed farming, requires a thorough understanding of the pertinent hydrological properties which includes soil water retention characteristics, available water capacity as well as plant available water capacity (PAWC) of the soils. The moisture retention characteristics of soils which provide information on the ability of soils for storing water and its subsequent availability to the crops as well as moisture releasing behaviour were studied for nine mapped soil units under varying physiographic positions in Mamring micro watershed of Darjeeling Himalayas in West Bengal. Variation in water retention characteristics was attributed to textural variations and it had been found that moisture retentivity at 33 kPa and 1500 kPa tension was significantly and positively correlated with clay, silt plus clay and organic carbon, whereas, negative correlation was observed with sand content, porosity and bulk density. The moisture release behaviour of the soils under different range of suctions did not varied widely due to differences in physiographic positions. Plant available water capacity for these soils were also studied and it had been found that the value of PAWC was highest for the soils under hill top ridge and summit (10-15 % slope) and lowest in lower side slopes having 25-33 % slope. Again variation in PAWC was also observed with land use systems and it followed the trend of forest > vegetable > cereals > fallow land uses.

Key words: Plant available water capacity, soil moisture retention, watershed

The water movements and efficient use of water resources, requires a thorough understanding of different hydrological properties including soil water retention characteristics, together with its available water capacity as well as plant available water capacity (PAWC). Soil water-retention characteristics (retention curves) are important soil properties as soil pore-size distribution directly determines the amount of water that can be retained by the soil at a given matric potential, and inversely the air-filled porosity (Hillel, 1982). The amount of soil water available for crop growth which is referred as Plant Available Water Capacity (PAWC) is determined by the storage capacity of the soil, the ability to recharge this store by surface water application and depth and distribution of root system (Gardner *et al*., 1984). Texture, organic carbon, CEC and bulk density are known to influence the retention and release of water by soil (Walia *et al*., 1999). Since the information on these aspects are lacking in this humid tropical belt under Darjeeling Himalayas, an attempt has been made to study the influence of soil properties on water retention and its subsequent release with increasing soil-water under varying physiography and land use systems.

MATERIALS AND METHODS

Mamring micro watershed lies between $88^0$18'48" to $88^0$20'14" E longitude and $26^0$56'27"to $26^0$57'15" N latitude, covering two villages Upper Mamring and Lower Mamring and a part of the Mahaldhram forest area with an area of 198 hectares. The area falls under humid sub-tropical climatic belt with mean annual air temperature is 17.1^{0}C, whereas mean maximum and mean minimum air temperature being 21.5 and 11.5 respectively. The mean annual precipitation is 2667.1 mm (about 83 % is received during June-September) which accounts for about 27 per cent of potential evapotranspiration (721.8 mm). The soils have surplus moisture (1938.9 mm) from June to September and remain dry from December to April.

The elevation of the micro watershed ranges from 4200 ft. to nearly 6500 ft. above msl. Geographically the area is parts of Sub-Himalayan Zone (Siwalik belt) with chief rocks are gneiss, schists, shale etc. Physiographically, the area is divided into 3 units *viz.*; hill top ridge and summit (10-15% slope), mountainous spur side slopes-upper (15-25%) and mountainous spur side slopes- lower (25-33%). Detailed soil survey was carried out in the study area and 7 dominant soil series with 9 soil mapping units were identified. The salient features of the different soil mapping units are shown in table-1.

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Table 1: Salient features of different soil mapping units of Mamring-Patle micro watershed

Soil map unit	Slope (%)	Colour	Drainage	Control section texture	Surface texture	Erosion	Land use
Soils of hill top ridge & summit							
M-1	10-15	Dark yellowish brown (10YR3/4 to 10YR3/6)	Well drained	Coarse loamy	Sandy loam	Moderate erosion	Forest trees
M-2	10-15	Dark brown (10YR3/3 to 10YR3/4)	Excessively drained	Coarse loamy	Sandy loam	Moderate erosion	Fallow, rocky and barren
M-9	10-15	Dark yellowish brown to yellowish brown (10 YR 4/6 to 10 YR 5/8)	Excessively drained	Loamy skeletal	Sandy loam	Very severe erosion	Radish, Carrot (Vegetables)
Soils of mountain talus and spur side slopes -upper							
M-3	15-25	Yellowish brown to strong brown (10YR5/6 and 7.5YR5/6 to 7.5YR5/8)	Excessively drained	Loamy skeletal	Sandy clay loam	Very severe erosion	Cardamom and private forest
M-4	15-25	Dark yellowish brown (10YR4/6)	Excessively drained	Coarse loamy	Sandy loam	Moderate erosion	Maize
M-5	15-25	Dark yellowish brown (10YR 3/6 to 10YR4/4)	Excessively drained	Loamy skeletal	Sandy loam	Very severe erosion	Vegetables
M-6	15-25	Dark yellowish brown (10YR3/4 to 10YR3/6)	Excessively drained	Coarse loamy	Sandy loam	Severe erosion	Maize
Soils of mountain talus and spur side slopes -lower							
M-7	25-33	Dark yellowish brown (10YR3/6)	Well drained	Loamy skeletal	Sandy loam	Severe erosion	Fallow, rocky barren
M-8	25-33	Dark brown to dark yellowish brown (10 YR 4/3 to 10 YR 3/4)	Excessively drained	Coarse loamy	Sandy loam	Very severe erosion	Thin forest

Physico-chemical properties of the selected soil samples were determined after necessary processing as per standard procedures (Page *et al.*, 1982). The water retention at different soil-water suctions was determined by pressure plate apparatus (Richards, 1965). In order to estimate the water actually available to the plants, Gardner *et al.* (1984) suggested the concept of plant available water capacity (PAWC) which is the profile soil water content and is calculated as –

$$\text{PAWC}=\sum_{Z=0}^{Z=RD}\frac{(W\max-Wdry).Db.\Delta..Z.10}{Dw}$$

Where,

PAWC = Plant available water capacity in mm

*W*max = Gravimetric water content at upper soil water storage (0.33 bar), gg^{-1}

*W*dry = Gravimetric water content at lower soil water storage (15 bar), gg^{-1}

Db = Bulk density at Wmax, gcm^{-3}

RD = Rooting depth

Δ Z = Depth interval;

Dw = Density of water (approximately 1 gcm^{-3})

It is considered as 1 m or to a depth of root limiting layer, whichever is shallower.

RESULTS AND DISCUSSION

The physico-chemical properties of the soils are presented in table-2. The soils were strong to extremely acidic in nature (pH 4.2 to 5.3) and generally the pH values increased with increase in depth with one or two exceptions. The organic carbon content of the soils was very high (0.51 to 4.68 %) and it gradually decreased with the increase in depth. The cation exchange capacity of the soils vary from 15.5 to 5.8 cmol (p+) Kg^{-1} in the surface layers and generally decreased at the sub-surface layers. Exchangeable Ca was the dominant cation followed by exchangeable Mg. Mostly the soils were sandy loam in texture. Porosity of the soils did not varied over a wide range (51.9 to 55.54 %) and generally decreased down the profile, while the bulk density of the soils ranged from 1.26 to 1.71 Mgm^{-3}.

Table 2: Physico-chemical properties for the soils of Mamring micro watershed

Mapping unit no.	Depth (cm)	pH	Sand (%)	Silt (%)	Clay (%)	Tex. class	Porosity (%)	OC (%)	CEC [Cmol (p+)kg^{-1}]	BD (Mgm^{-3})
1	0-14	4.9	68.8	19.5	11.7	sl	54.99	2.68	15.50	1.64
	14-37	5.2	65.2	21.7	13.1	sl	54.67	2.40	13.40	1.54
	37-75	5.3	68.5	18.2	13.3	sl	54.97	1.96	13.10	1.62
2	0-20	4.2	68.3	24.4	7.3	sl	54.95	2.15	6.80	1.60
	20-48	4.5	72.3	15.6	12.1	sl	55.31	0.51	4.20	1.69
3	0-23	4.9	52.7	26.8	20.5	scl	53.53	2.16	9.50	1.34
	23-56	4.6	45.7	36.4	17.9	l	51.90	1.02	5.50	1.26
	56-80	4.7	50.4	28.2	21.4	scl	53.33	4.68	5.30	1.33
	80-125	4.7	50	26.7	23.3	scl	53.29	4.45	5.40	1.33
4	0-14	4.4	65.7	18.3	16	sl	54.71	1.95	7.00	1.56
	14-27	4.6	65.1	24.2	10.7	sl	54.66	1.18	4.80	1.59
5	0-19	4.7	71.1	17.6	11.3	sl	55.20	2.81	9.50	1.65
	19-40	5.0	71.3	18.3	10.4	sl	55.22	0.90	4.10	1.63
	40-75	5.2	73.2	19.5	7.3	sl	55.39	0.61	4.40	1.71
6	0-21	4.5	64.0	21.5	14.5	sl	54.56	2.92	6.30	1.58
	21-48	4.2	66.0	25.9	8.1	sl	54.74	2.04	6.20	1.60
7	0-16	4.6	68.3	19.6	12.1	sl	54.95	2.77	7.20	1.60
8	0-14	4.4	67.5	21.6	10.9	sl	54.88	1.87	5.80	1.59
	14-44	4.5	67.9	20.8	11.3	sl	54.91	1.30	4.70	1.59
	44-65	4.6	66.2	20.5	13.3	sl	54.76	4.41	4.50	1.59
9	0-14	4.4	57.8	31.2	11.0	sl	54.00	3.25	7.00	1.34
	14-46	4.5	58.8	33.5	7.7	sl	54.09	1.62	4.30	1.36
	46-86	4.8	59.5	33.2	7.3	sl	54.15	0.81	3.40	1.35
	86-120	4.6	72.0	19.2	8.8	ls	55.54	0.51	4.80	1.51

Soil water relationships

Soil water retention characterizes the relationship between soil water content and matric potential. The moisture content versus matric suction relationship (moisture characteristics curve) indicates the behaviour of the soil to progressive release of moisture at increasing soil water suctions. The data in table- 3 as depicted in figure (Fig. 1) showed percent volumetric moisture content (cc cc^{-1}) at different matric suctions. The moisture content at field capacity (0.33 bar) of soils in different physiographic locations varies from 9.2 to 15.0 percent (cc cc^{-1}) and at 15 bar it varies from 2.1 to 5.5 percent (cc cc^{-1}). This variation is attributed to textural variation of the different soils as well as to their positions in different physiographic locations of the watershed. In the hill top ridge and summit physiography the soils under the mapping units M-1, M-2 and M-9, the moisture content on an average at 0.33 bar and 15 bar suction was 12.4 and 3.6 percent respectively. In the upper side slopes having soils with mapping unit from M-3 to M-6, the average moisture content at 0.33 bar and 15 bar suction was 13.4 and 4.3 percent respectively while in the lower side slopes (map unit M-7 and M-8) the moisture content varied from 13.6 to 4.0 percent at 0.33 bar and 15 bar respectively.

Table- 5 gives the weighted soil moisture content at different matric suctions to give a weighted value for each mapping unit. The table indicates that the M-5 soils released the highest percentage of moisture (78 percent) upto 5 bar matric suctions, followed by M-2 and M-8 soils. Between 5 and 10 bar suctions the release of moisture by different soils showed more or less uniform trend ranging from 11 to 13 percent. In the matric suction range between 10 to 15 bar the maximum limit of 13 percent moisture release was observed in M-3 and M-4 soils. It was observed from the data that there was little variation in moisture release under different suctions due to change in physiographic positions of different soils.

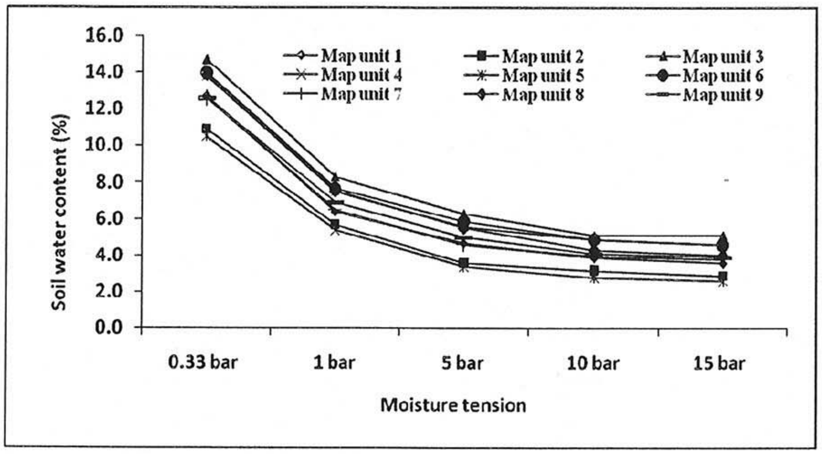

Fig. 1: Moisture retention characteristics for the soils of Mamring micro watersheds

Table 3: Soil water retention characteristics of different soil mapping units

Mapping unit no.	Depth (cm)	Water content at (mm^{-1})		AWC ($mm\ m^{-1}$)	PAWC (mm)
		33 kPa	1500 kPa		
1	0-14	0.122	0.032	147.6	109
	14-37	0.136	0.045	140.1	
	37-75	0.124	0.033	147.4	
2	0-20	0.128	0.035	148.8	63
	20-48	0.095	0.025	118.3	
3	0-23	0.145	0.048	130.0	126
	23-56	0.150	0.055	119.7	
	56-80	0.147	0.049	130.3	
	80-125+	0.147	0.050	129.0	
4	0-14	0.138	0.046	143.5	39
	14-27	0.139	0.046	147.7	
5	0-19	0.115	0.030	140.3	99
	19-40	0.117	0.031	140.2	
	40-75+	0.092	0.021	121.4	
6	0-21	0.141	0.048	147.1	71
	21-48+	0.139	0.045	150.4	
7	0-16	0.126	0.038	140.4	22
8	0-14	0.135	0.039	153.0	102
	14-44	0.134	0.038	153.1	
	44-65	0.148	0.045	163.6	
9	0-14	0.144	0.042	136.7	124
	14-46	0.138	0.045	126.5	
	46-86	0.136	0.044	124.2	
	86-120	0.096	0.025	107.2	

Table 4: Plant available water capacity under different physiographic positions for the soils of Mamring micro watershed

Physiography	AWC (mm m^{-1})	PAWC (mm)
Hill top ridge & summit	133.0	99
Side slopes -upper	136.3	84
Side slopes-lower	152.5	62

Table 5: Moisture release (%) behaviour for the soils of Mamring micro watershed

Physiography	0.33-5 bar	5-10 bar	10-15 bar	0.33-5 bar	5-10 bar	10-15 bar
	76	12	12			
Hill top ridge & summit	77	12	11	76.0	12.3	11.7
	75	13	12			
	73	13	13			
Side slopes -upper	73	13	13	74.8	12.5	12.3
	78	11	11			
	75	13	12			
Side slopes-lower	75	13	12	76.0	12.5	11.5
	77	12	11			

Table 6: Correlation coefficients (r) between soil properties and soil water (w/w) at different tensions

Soil properties	33 kPa	1500 kPa
Sand	-0.747**	-0.817**
Silt	0.623**	0.670**
Clay	0.498*	0.561**
Silt + Clay	0.747**	0.817**
CEC	0.017ns	-0.068ns
Porosity	-0.714**	-0.796**
Bulk density	-0.629**	-0.696**
Organic carbon	0.569**	0.455*

*Note: *, ** Significant at 5 % and 1% level of probability, respectively*

Available water capacity

Available water capacity of soils is generally considered as the amount of water held between soil water suctions corresponding to the field capacity (0.33 bar) and permanent wilting point (15 bar).

It had been found (Table 3 and 4)) that average available water capacity in soils of hill top ridge and summit was 133.0 mm per m and the plant available water capacity was 99 mm. The soils on upper side slopes had available water capacity and plant available water capacity values of 136.3 mm per m and 84 mm, respectively on an average whereas, the same for the soils of the lower side slopes was 152.5 mm per m and 62 mm, respectively. Perusal of the data reveals that the PAWC values varied from 22 to 126 mm as the soil depth ranged from very shallow depth (16 cm) to very deep (more than 1 m). The M-3 and M-9 soils showed the maximum PAWC values. The other soils M-1and M-5 having similar soil depth show variation in PAWC values (109 mm and 99 mm respectively) due to variation in texture. It had been observed by Gardner *et al.* (1984) that the plant available water capacity is limited by the rooting depth.

The plant available water capacity under different land use systems showed that it was highest in the forest soils followed by vegetables, cereals and fallow land which is depicted in fig. 2. This may be attributed to the rooting depth of the crops under different land use systems and also the amount of organic matter content in the soils.

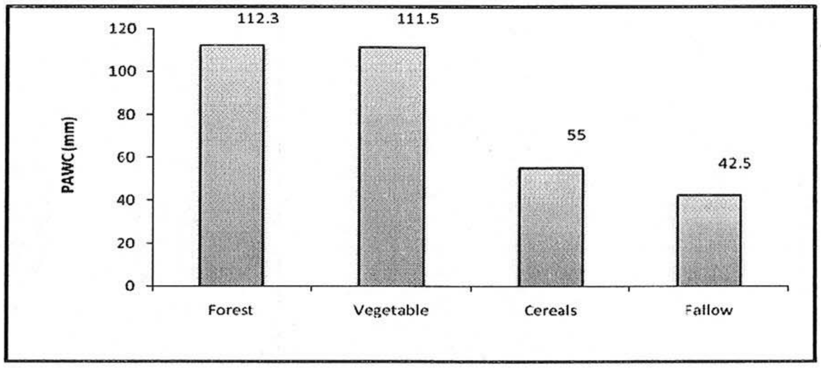

Fig. 2: PAWC under different land use system of Mamring micro watershed

Correlation coefficient

The water retentivity at 33 kPa and 1500 kPa tension is significantly and positively correlated with silt, clay, silt + clay and organic carbon content and negatively correlated with sand, porosity and bulk density (Table 6). Thus, it may be concluded that amount and nature of clay have a dominant role in water retention of the soils. Similar results were reported by Velayutham and Raj (1977), Challa and Gaikawad (1987) and Bruand and Tessier (2000). Negative effect of bulk density over the water retentivity both at 33 kPa and 1500 kPa was also noticed by Rawls *et al.* (1982). The positive effect of organic carbon on water retentivity of soil was prominent due to their higher presence in the soils. The rate of release of moisture is more gradual in fine textured soils than that of coarse textured ones. Similar results were also noticed by Chinchamalatpure *et al.* (1999).

The results revealed that the soil moisture behaviour in terms of water retentivity under different suctions didn't vary widely with the changes in physiographic positions for the nine mapped soil units under this hilly watershed of Darjeeling Himalayas. The plant available water capacity (PAWC) decreased with the increasing slope percentage but the same was increased with the increasing soil depth. PAWC variation under different land use systems showed that it was highest in the forest soils and lowest in the barren fallow lands. Fluctuations in water retentivity under different level of suctions are highly affected by the textural variations, organic matter content and bulk density of the soils.

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