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Water use efficiency of rainfed soybean-safflower cropping system in shrink-swell soils of Central India

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Abstract : The field experiments conducted during 1997-98 and 1998-99 involving soybean-safflower cropping system in Nagpur, Maharashtra indicate highest water expense efficiency in Vertic Haplustepts (S2) followed by clayey Lithic Ustorthent (S1) and Typic Haplusterts (S3) in both the years for soybean. Similarly highest water expense efficiency (WEE) was obtained in S3 followed by S2 and S1 soils in both the years for safflower. The higher WEE was observed during 1997-98 than 1998-99. The water expense efficiency was 15.05, 18.40 and 18.62 kg/ha/cm in S1, S2 and S3 soils, respectively during 1997-98 and 18.02, 20.04 and 20.12 kg/ha/cm, respectively during 1998-99 which indicate that the WEE for soybean-safflower cropping systems was similar in S2 and S3 soils despite variation in rainfall distribution in the years.
Additional keywords : Rainfed, soil moisture, cropping system.

Introduction

Water is a driving variable in agriculture and profitability of a cropping system under rainfed conditions depends on efficient use of incident precipitation. Soil and crop management are the secondary variables that greatly modify WUE. The WUE is a measure of performance indicator of a cropping system because it reflects the total moisture availability and its utilization by the system. As a whole it integrate the influences of factors such as exploitable soil volume and rooting depth interaction.

In Central India, the common cropping system followed in shrink-swell soils under rainfed condition is soybean-gram/ sorghum-gram or sole cotton (Hajare *et al* 1994). The yield of the crops are generally low due to low harvest index, flower drop, indeterminate growth habit, erratic rainfall distribution, shallow soil, poor drainability and traditional crop management practices. This necessitated the search for profitable cropping system in shrink-swell soils than the existing ones, associated with higher WEE. Through present study an attempt has been made to compute the WUE of soybean–safflower cropping sequence in the rainfed environment of Nagpur, Maharashtra.

Materials and methods

The experiments were conducted during 1997-98 and 1998-99 at Futala Farm, College of Agriculture, Nagpur, Maharashtra. The experimental soils were clayey, Lithic Ustorthents (S1); fine, Vertic Haplustepts (S2) and fine, Typic Haplusterts (S3). The sowing of soybean/safflower was done at four places in each soils following randomisation. Soybean *var.* PKV 25 was sown on 10th July and 29th June during 1997 and 1998, respectively after the onset of monsoon. After harvest of soybean, safflower *var.* Bhima was sown in the same plots on 10th and 15th October during 1997-98 and 1998-99 respectively. The periodic soil moisture sampling was done by the screw auger at an interval of 15 days from the mean depth of 10 cm (0-20), 30 cm (20-40) and 60 cm (40-80). The water use (ETa) was computed from the rainfall plus soil moisture depletion at different growth phases. Since water use efficiency (WUE) and water expense efficiency (WEE) carry the same meaning *i.e.* water utilization per unit biomass production, WEE was used instead of WUE for purpose of interpretation, as the deep percolation loss of water could not be estimated in the rainy season. Weekly rainfall and pan evaporation data were collected from the observatory situated at College Farm. PET was computed as pan evaporation data multiplied by factor 0.8. WEE (Walmi 1988) was estimated as the ratio of seed yield in kg/ha to the cumulative water use in cm during the crop-

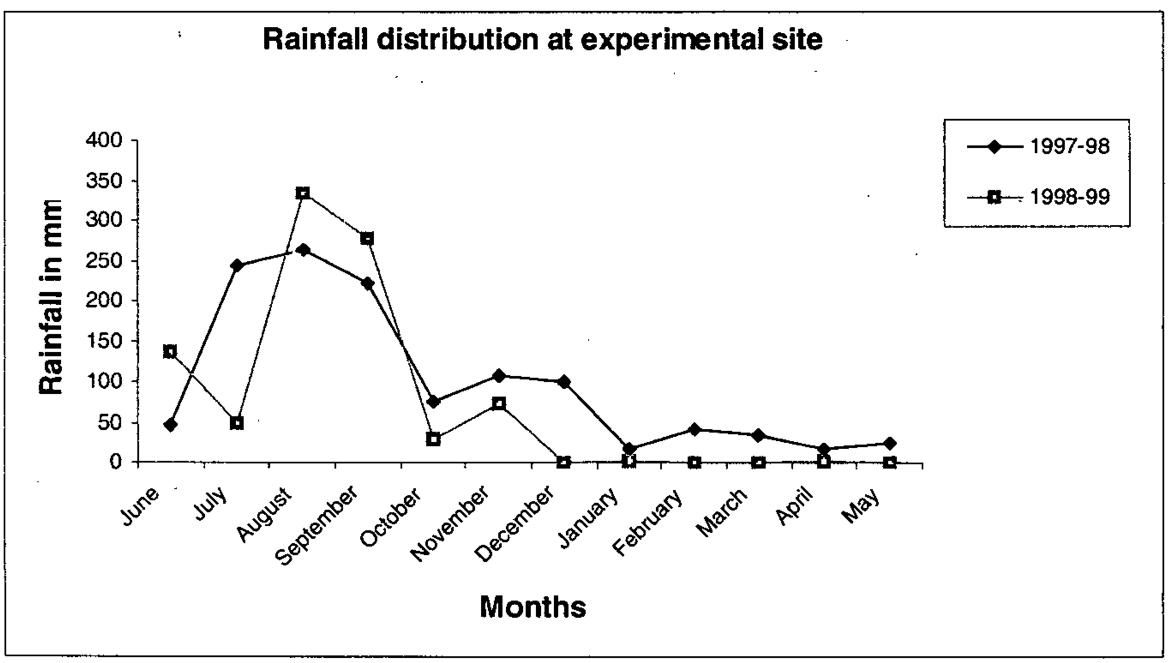

Fig.1. Rainfall distribution at experimental site.

Table 1. Physical characteristics of the experimental soils.

Horizon	**Depth (cm)**	**Particle - size distribution (mm)**			Moisture content			
		Sand (2.0-0.02) (%)	Silt (0.02-0.002) (%)	Clay (<0.002) (%)	33 kPa (%)	1500 kPa (%)	Available water content (%)	Drainage
		S1 : Clayey, Smectific, hyperthermic Lithic Ustorthent						
AP	0-12	51.2	13.3	35.5	25.3	14.4	10.9	Well-drained
A2	12-22	52.5	12.5	35.0	25.0	12.9	12.1	
Cr	22-37	Weathered basalt						
		S2 : Fine, Smectific, hyperthermic Vertic Haplustepts						
AP	0-18	30.6	23.9	45.5	35.0	18.0	17.0	Moderately
Bw1	18-30	28.8	22.0	49.2	38.0	19.0	19.0	Well-drained
Bw2	30-50	25.6	21.0	53.4	41.2	20.5	20.7	
Bw3	50-60	35.7	17.5	47.1	36.3	18.9	17.4	
Cr	60-82	Weathered basalt						
		S3 : Fine, Smectific, hyperthermic (calcareous) Typic Haplusterts						
AP	0-19	13.5	31.9	54.6	44.1	22.0	22.1	Imperfectly
Bw	19-33	10.8	30.7	58.5	44.9	22.5	22.4	drained
Bss1	33-62	9.0	29.5	61.5	47.6	23.3	24.3	
Bss2	62-70	18.5	27.0	54.5	42.9	21.3	21.6	
BCk	90-120	25.7	24.2	50.1	40.0	20.8	20.2	

Table 2. Chemical properties of the experimental soils.

Horizn	Depth (cm)	pH (1 : 2)	OC (%)	$CaCO_3$ (%)	EC dSm^{-1} (1 : 2)	Exchangeable cations coml (p+) kg^{-1} Ca	Mg	Na	K	C.E.C	Availble nutrients Kg/ha N	P_2O_5	K_2O
S1 : Clayey, Smectific, hyperthermic Lithic Ustorthent													
AP	0-12	8.0	0.51	0.4	0.27	26.3	6.91	0.54	0.25	26.05	121.61	27.90	167.00
A2	12-22	8.1	0.44	0.9	0.23	29.0	7.08	0.32	0.11	25.18	97.33	22.14	70.40
S2 : Fine, Smectific, hyperthermic Vertic Haplustepts													
AP	0-18	7.6	0.64	1.7	0.12	28.4	9.55	0.25	0.19	44.30	192.62	27.82	123.20
Bw1	18-30	7.7	0.56	1.5	0.12	33.9	10.86	0.22	0.14	46.04	181.33	27.30	122.00
Bw2	30-50	7.9	0.50	2.9	0.10	36.8	11.19	0.25	0.19	43.86	179.60	24.12	119.20
Bw3	50-60	8.1	0.38	14.5	0.10	39.0	11.19	0.44	0.16	49.50	143.80	23.18	116.80
S3 : Fine, Smectific, hyperthermic (calcareous) Typic Haplusterts													
AP	0-19	8.2	0.81	3.1	0.18	48.0	6.42	0.22	0.63	52.73	240.21	14.43	369.50
Bw_1	19-33	8.3	0.80	8.9	0.13	47.3	6.74	0.28	0.58	53.63	163.37	15.90	325.50
Bss1	33-62	8.4	0.63	8.5	0.14	49.5	10.04	0.23	0.56	55.46	213.37	13.59	334.30
Bss2	62-75	8.6	0.38	18.6	0.15	39.4	7.56	0.20	0.49	52.09	191.52	13.30	281.52
BCk	90-120	8.9	0.31	15.0	0.16	32.2	7.56	0.20	0.35	50. 2	-	-	-

Table 3. Profile water balance and water expense efficiency (WEE) of soybean in different soils during 1997 and 1998.

Soils	Growth stages	Profile water contribution		Rainfall (cm)		Crop water expenses (cm)		Yield (kg/ha)		Water use efficiency (kg/ha/cm)		Mean (kg/ha/cm)
		1997	1998	1997	1998	1997	1998	1997	1998	1997	1998	
Lithic Ustorthents	Seedlings (0-15) DAS	-0.62	-0.81	2.75	1.45	2.13	0.64	870	1029	15.89	20.76	18.32
	Vegetative (15-30) DAS	+ 0.78	+1.12	14.04	2.85	14.82	3.97					
	Flowering and seed formation (30-60) DAS	-0.71	+0.03	30.76	36.20	30.05	36.23					
	Maturity (60-75) DAS	+ 0.40	-0.68	7.35	9.40	7.75	8.72					
	Total					54.75	49.56					
Vertic Haplustepts	Seedlings (0-15) DAS	+3.40	0.33	2.75	1.45	6.15	1.12	998	1145	18 15	23.10	20.62
	Vegetative (15-30) DAS	+0.65	+1.23	14.04	2.85	14.69	4.08					
	Flowering and seed formation (30-60) DAS	-5.03	-0.83	30.76	36.20	25.73	35.37					
	Maturity (60-75) DAS	+1.04	-0.41	7.35	9.40	8.39	8.99					
	Total					54.96	49.56					
Typic Haplusterts	Seedlings (0-15) DAS	+2.60	-1.93	2.75	1.45	5.35	0.06	800	947	15.18	19.53	17.35
	Vegetative (15-30) DAS	+1.37	+1.75	14.04	2.85	15.41	4.60					
	Flowering and seed formation (30-60) DAS	-4.92	-0.78	30.76	36.20	25.84	35.42					
	Maturity (60-75) DAS	-1.28	-1.00	7.35	9.40	6.07	8.40					
	Total					52.67	48.48					

Table 4. Profile water balance and water use efficiency (WEE) of safflower in different soils during 1997-98 and 1998-99.

Soils	Growth stages	Profile water contribution (cm)		Rainfall (cm)		Crop water expenses (cm)		Yield (kg/ha)		Water use efficiency kg/ha/cm		Mean kg/ha/cm
		1997-98	1998-99	1997-98	1998-99	1997-98	1998-99	1997-98	1998-99	1997-98	1998-99	
Lithic Ustorthents	Seedlings (0-30) DAS	-2.55	-2.18	6.42	13.86	3.87	11.68	325	295	11.14	16.45	13.79
	Vegetative (30-50) DAS	+1.37	+2.68	11.35	0.96	12.72	3.64					
	Flowering and seed formation (50-90) DAS	+0.87	+1.96	9.40	0.0	10.27	1.96					
	Maturity (90-105) DAS	+2.30	+1.65	0.0	0.0	2.30	0.65					
	Total					29.16	17.93					
Vertic Haplustepts	Seedlings (0-30) DAS	-5.54	-0.50	6.42	13.86	0.88	13.36	535	465	15.53	14.80	15.04
	Vegetative (30-50) DAS	+1.64	+6.37	11.35	0.96	12.99	7.33					
	Flowering and seed formation (50-90) DAS	+3.18	+8.27	9.40	0.0	12.58	8.27					
	Maturity (90-105) DAS	+2.09	+1.95	0.0	0.0	7.99	1.95					
	Total					34.44	30.91					
Typic Haplusterts	Seedlings (0-30) DAS	-3.62	-1.36	6.42	13.86	2.80	12.5	678	580	19.44	18.95	19.09
	Vegetative (30-50) DAS	+2.52	+5.72	11.35	0.96	13.87	6.68					
	Flowering and seed formation (50-90) DAS	+2.60	+7.48	5.90	0.0	11.00	7.28					
	Maturity (90-105) DAS	+1.30	+3.94	0.0	0.0	7.20	3.94					
	Total					34.87	30.40					

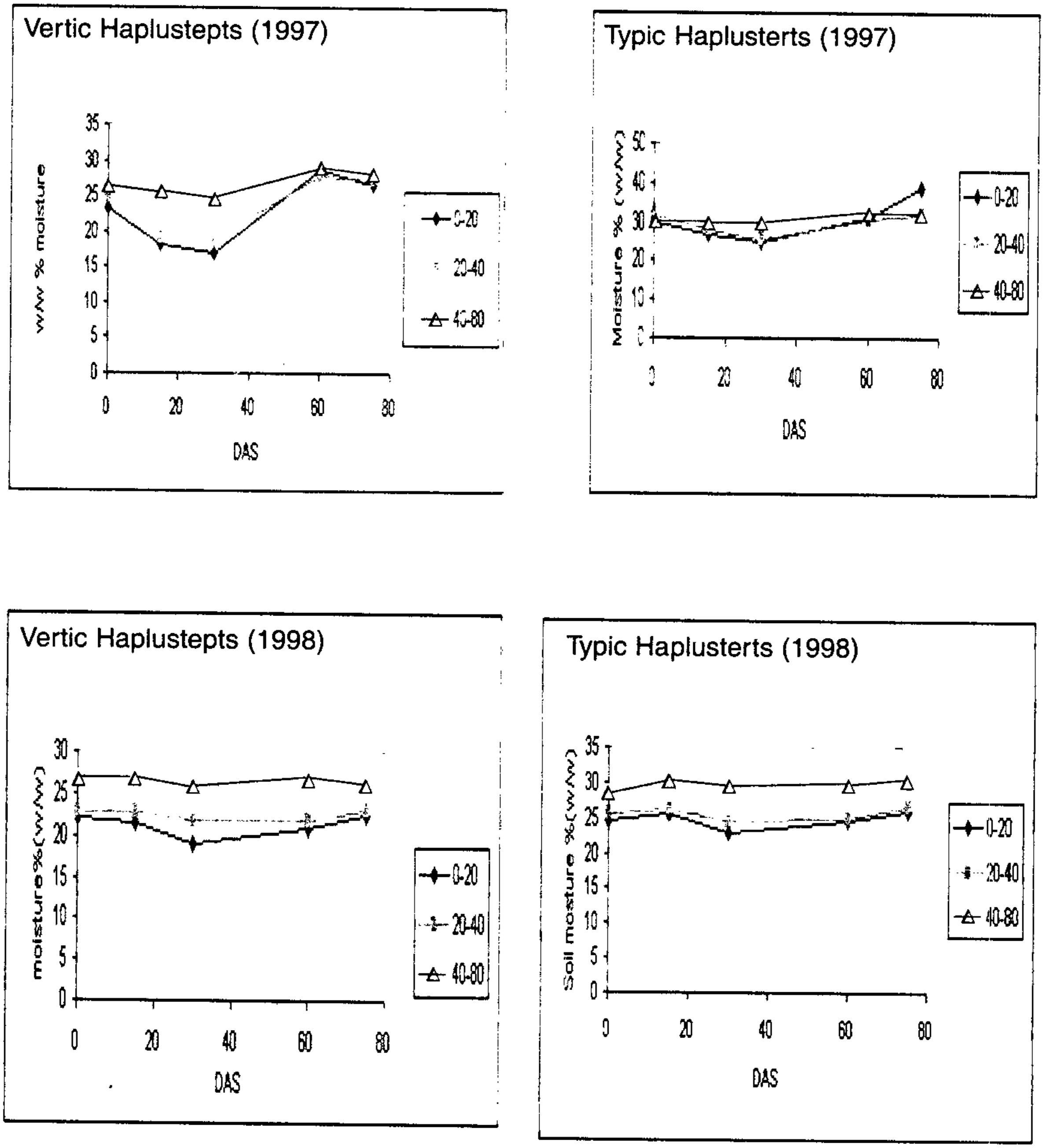

Fig. 2 :- Soil moisture distribution in different soils under rainfed soybean

Table 5. Water use efficiency of soybean-safflower cropping sequence during 1997-98 and 1998-99.

Soils	Soybean-safflower 1997-98			Soybean-safflower 1998-99			
	Total water use (cm)	Soybean yield equivalent (kg/ha)	Use efficiency	Total water use (cm)	Soybean yield equivalent (kg/ha)	Use efficiency	Mean WEE
S1	83.91	1263	15.05	67.49	1417	20.99	18.02
S2	89.40	1645	18.40	80.97	1756	21.68	20.04
S3	87.00	1620	18.62	79.08	1710	21.62	20.12

growing season for soybean and safflower.

Results and Discussion

The salient properties of soils have been given in table 1 and 2. The data indicate that Vertisol by virtue of having higher clay had higher water retention at 33 and 1500 kpa than the other two soils.

Soil moisture distribution and WEE of soybean

The data on rainfall distribution (Fig. 1) indicate that there was 1283 mm and 895.9 mm rainfall in 1997 and 1998, respectively but its distribution varied significantly. There was 126 mm and 21.5 mm rainfall during regetative period (25 DAS) in 1997 and 1998, respectively. Similarly there was 223.4 mm and 220.7 mm. during flowering to pod formation period (25 to 45 DAS in 1997 and 1998, respectively. At grain maturity, it was 84.2 mm and 142.5 mm rainfall in 1997 and 1998, respectively. Although soybean crop received low rainfall at earlier stage during 1998 but final yield was higher as the other two stages, have sufficient rainfall to meet the ET demand. Hajare *et al.* (2001) observed that any moisture stress at flowering to pod formation stage significantly affect the grain yield of soybean. The high rainfall at physical maturity did not lower the yield. In the year 1997, the highest soil moisture was observed for S3 (27 per cent on an average) which was 11.80 and 28.8 per cent higher than S2 and S1 soils, respectively. In the year 1998, the soil moisture content at different growth phases was relatively lower but at harvest, due to rain in the previous week, the soil moisture was high for all the soils during 1997-98. The distribution of moisture (Fig. 2) for Vertic Haplustepts (S2) and Typic Haplusterts (S3) also indicate that the low moisture was retained in S2 soil during 1997 because of high soil moisture extraction by soybean plant during initial to mid flowering stages (25-45 days) as compared to S3 soil. The regular rainfall after 50 DAS of soybean resulted in higher moisture in the soil profile.

The total rainfall received during growing period of soybean was 549 mm in 1997 and 442 mm in 1998. The water use computed from moisture data indicate that

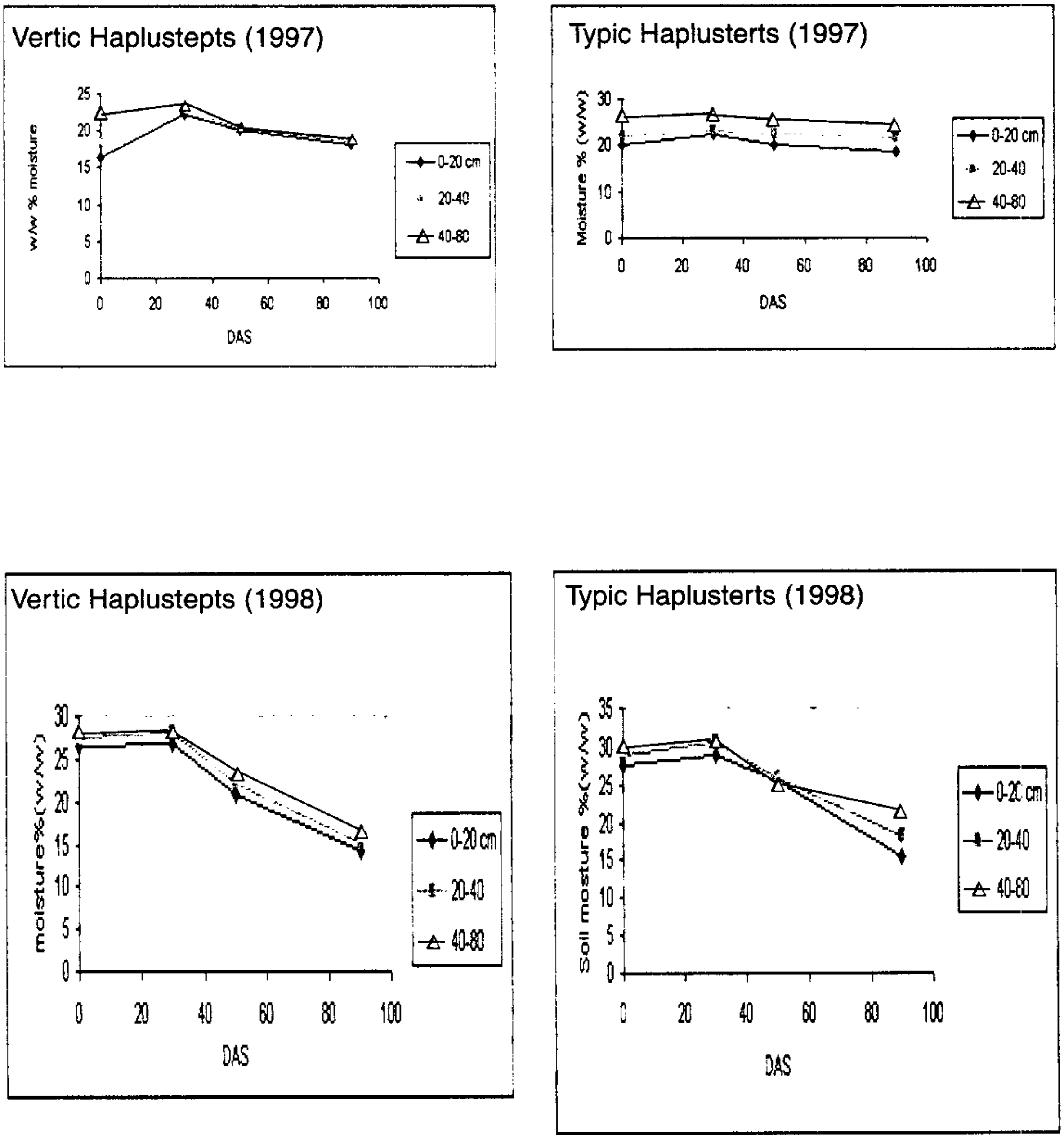

Fig 3. :- Soil moisture distribution in different soils under rainfed safflower

total water use of the crop in 1997 varied from 52.67 cm to 54.96 cm and 48.48 cm to 49.5 cm in 1998. The highest WEE was obtained in S2 soil followed by S1 and S3 in both the years. During 1997-98, WEE varied from 15.18 to 18.15 kg/ha/cm and 19.53 to 23.10 kg/ha/cm in 1998-99. The highest WEE was obtained in 1998 due to low rainfall during vegetative stage. The lowest WEE (15.18 kg/ha/cm) was recorded for soybean in S3 may be due to poor drainage. The results are in conformity with those reported by Gupta and Varade (1988) and Kool *et al.* (1995). The moisture use efficiency was higher in 1998 due to higher available soil water which has met the requirements of soybean during different growth stages.

Soil moisture distribution and WEE in safflower

The periodic soil moisture distribution for safflower is depicted in fig. 3 and moisture use data are presented in table 3 and 4 for 1997-98 and 1998-99 respectively. The data indicate that soil moisture during crop growth remained at lower tension in 1997-98 than 1998-99. This is probably due to intermittent rainfall during 1997-98.

The total water-use of safflower followed a different trend than that of soybean in both the years because of differential moisture use efficiency and production potential (Peterson *et al.* 1996). The total moisture use ranged from 29 to 35 cm and 18 to 31 cm during 1997-98 and 1998-99, respectively. The total water expense during 1997-98 was 10 and 14 per cent higher as compared to 1998-99 for S2 and S3 soils, respectively. The moisture use in S1 soil varied widely during 1997-98 because of shallow depth. Safflower being deep-rooted crop probably extracted moisture even from murrum layer, as relatively higher rainfall was received during the crop growth stages.

The WEE varied from 11.14 to 19.44 and 14.80 and 18.95 kg/ha/cm during 1997-98 and 1998-99, respectively. The well-distributed rainfall during 1997-98 resulted in higher WEE. The highest WEE (19.44 kg/ha/cm) was obtained in S3 soil during 1997-98 and lowest WEE (11.14 kg/ha/cm) in S1 soil. Similar observation was also reported by Hajare *et al.* (1997) for chickpea. The peak water demand of soybean crop occur during flowering to early pod filling stage and stress during that period leads to biomass reduction (Doss 1974 and Nasser *et al.* 1997).

WEE soybean-safflower cropping sequence

The total WEE in soybean-safflower cropping sequence is computed by calculating the soybean grain equivalent and presented in table 5 for both the years. The water expense efficiency was 15.05, 18.40 and 18.62 in S1, S2 and S3 soils, respectively during 1997-98 and 18.02, 20.04 and 20.12 kg/ha/cm, respectively during 1998-99.

The wide variation in WEE value in S1 soil for both the years indicate that the cropping sequence tested is not appropriate in Lithic Ustorthent because of shallow depth of soil which causes frequent moisture stress. The WEE in S2 and S3 soils were similar despite of wide variation in rainfall distribution in both the years because of their water holding capacity and capacity of safflower to absorb water and nutrients from deeper layers of soil. The data confirms that the WEE of a cropping sequence is always higher than a single crop. Peterson *et al.* (1996) also recorded similar observations for croping sequence in rainfed environment.

The finding further indicate that the WEE of deep Vertic Haplustepts and Typic Haplusterts are very comparable when total cropping systems is considered because of their similar properties in terms of clay, depth, calcareous and water holding capacity *etc.* although they belong to different order.

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